High-Speed Ground Transportation Noise and Vibration Impact Assessment

U. S. Department
of Transportation
Federal Railroad Administration

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Office of Railroad Development
Washington, D.C. 20590

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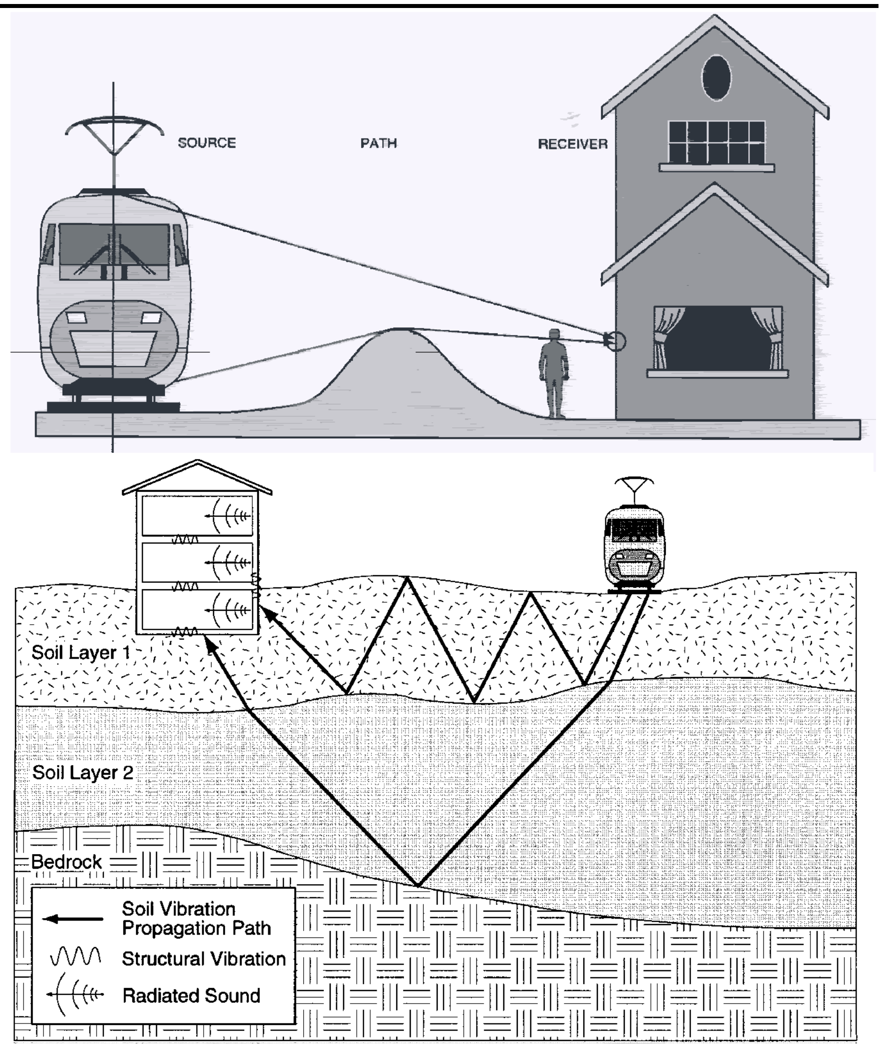

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Chapter 1

INTRODUCTION

1.1 PURPOSE

This manual provides procedures for the assessment of potential noise and vibration impacts resulting from proposed high-speed ground transportation (HSGT) projects, including high-speed rail using traditional steel-wheel on steel-rail technology and magnetically levitated (maglev) systems[1]. This document reflects the result of research conducted for the Federal Railroad Administration (FRA) and is presented as part of FRA's efforts to promote the consideration of HSGT as a transportation option in those intercity corridors where it has the potential to be a cost effective and environmentally sound component of the intermodal transportation system. The National Environmental Policy Act and related statutes, regulations and orders (NEPA) mandate consideration of potential impacts on the human and natural environment as part of the decision making process when Federal agencies evaluate proposals to fund or otherwise approve major actions. Most states have similar environmental review requirements.

Experience during previous environmental impact reviews of high-speed rail projects has shown that possible increases in noise and vibration are frequently among the potential impacts of most concern to residents in the vicinity of the proposed project. As the interest in HSGT grows and environmental review of HSGT projects are initiated in several locations across the country, it becomes clear to FRA that there is a need to provide a standardized set of procedures for the evaluation of noise and vibration impacts. There is also a need to provide guidance to promoters and designers of HSGT projects on ways in which the design of those projects can incorporate measures that address these concerns. And there is a need for

[1]For brevity, this manual uses the terms "high speed ground transportation" and "high speed rail" interchangeably, both referring to high speed guided intercity transportation.

providing a means through which public agency reviewers of projects can determine where and to what extent the public benefits of HSGT justify investment in impact mitigation. This manual attempts to fulfill these needs.

1.2 ORGANIZATION OF THE MANUAL

This manual is divided into two parts, noise and vibration. Each part has a parallel organization, which addresses the following topics:

Topic	Noise	Vibration
Basic Concepts	Chapter 2	Chapter 6
Criteria	Chapter 3	Chapter 7
Initial Evaluation	Chapter 4	Chapter 8
Detailed Analysis	Chapter 5	Chapter 9
Construction Noise/Vibration	Chapter 10.1	Chapter 10.2
Documentation	Chapter 11	Chapter 11

Appendices

A. Background for Noise Concepts
B. Existing Noise Determination
C. Noise Source Reference Level Determination
D. Glossary of Terms

Chapter 2

BASICS OF HIGH-SPEED RAIL NOISE

Noise from high-speed rail systems is similar to noise from other rail systems except for a few unique features resulting from the higher speeds of travel. The rail systems defined as "high-speed" are primarily steel wheeled, both electrically powered and fossil fueled, capable of maximum speeds of 125 mph and greater. Noise characteristics of these trains vary considerably as speed increases. Consequently, this manual sub-divides these systems into three categories:

- “high-speed,” with a maximum speed between 125 and 150 mph,
- “very high-speed,” with a maximum speed between 200 and 250 mph, and
- “maglev,” magnetically levitated and powered systems representing the upper range of speed performance up to 300 mph, although no such systems currently operate in revenue service.[1]

Because ancillary sources are not unique to high speed ground transportation systems, noise from electrical substations, maintenance facilities, yards, and stations, are not addressed in this manual. These noise sources are substantially the same for any type of rail system and do not have characteristics specific to high-speed rail systems. Noise and vibration from lower speed trains are also not addressed. The methods described in the corresponding transit noise manual from Federal Transit Administration are applicable.[2]

This chapter discusses the basic concepts of high-speed rail noise to provide background for the

[1]Noise from maglev in this manual is based principally on research and test track data from the German TransRapid System, currently under development.

[2]U.S. Department of Transportation, Federal Transit Administration, “Transit Noise and Vibration Impact Assessment," Final Report, DOT-T-95-16, April 1995.

assessment procedures presented in Chapters 4 and 5. Noise from a ground transportation system is often expressed in terms of a Source-Path-Receiver framework. This framework is sketched in Figure 2-1 and is central to all environmental noise studies. Each project **source** generates close-by noise levels, which depend upon the type of source and its operating characteristics. Then, along the propagation **path** between all sources and receivers, noise levels are reduced (attenuated) by distance, intervening obstacles, and other factors. Finally, at each **receiver**, noise combines from all sources and may interfere with receiver activities.

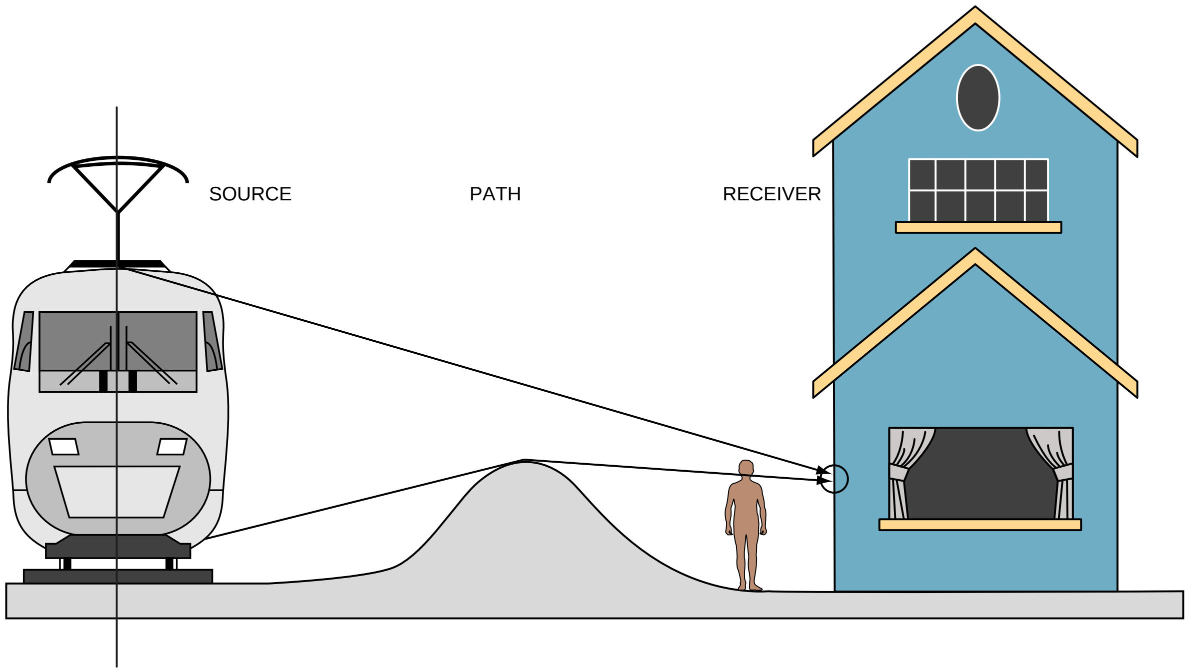

Figure 2-1 The Source-Path-Receiver Framework

This chapter emphasizes the **sources** of noise from high-speed trains and, to a lesser extent, the **path** component, which includes aspects such as sound attenuation with increasing distance from the source, excess attenuation due to atmospheric absorption and ground effects, and acoustic shielding by terrain, sound barriers, or intervening buildings.

In brief, this chapter contains:

- a summary of the **noise descriptors** used in this manual for high-speed rail noise (Section 2.1);
- an overview of noise **sources**, including a list of major sources specific to high-speed rail systems and discussion of noise-generation mechanisms (Section 2.2);
- an overview of noise **paths**, with a discussion of the various attenuating mechanisms on the path between source and receiver (Section 2.3);

- a summary of the theoretical **models** used to predict high-speed rail noise, in addition to actual measurement data from existing high-speed rail systems (Section 2.4).

2.1 NOISE DESCRIPTORS

The universal descriptor used for environmental noise is the A-weighted sound level. It describes the level of noise measured at a receiver at any moment in time and is read directly from noise-monitoring equipment, with the weighting switch set on "A." Typical A-weighted sound levels for high-speed rail and other sources are shown in Figure 2-2. The high-speed rail sources are described further in Section 2.4.

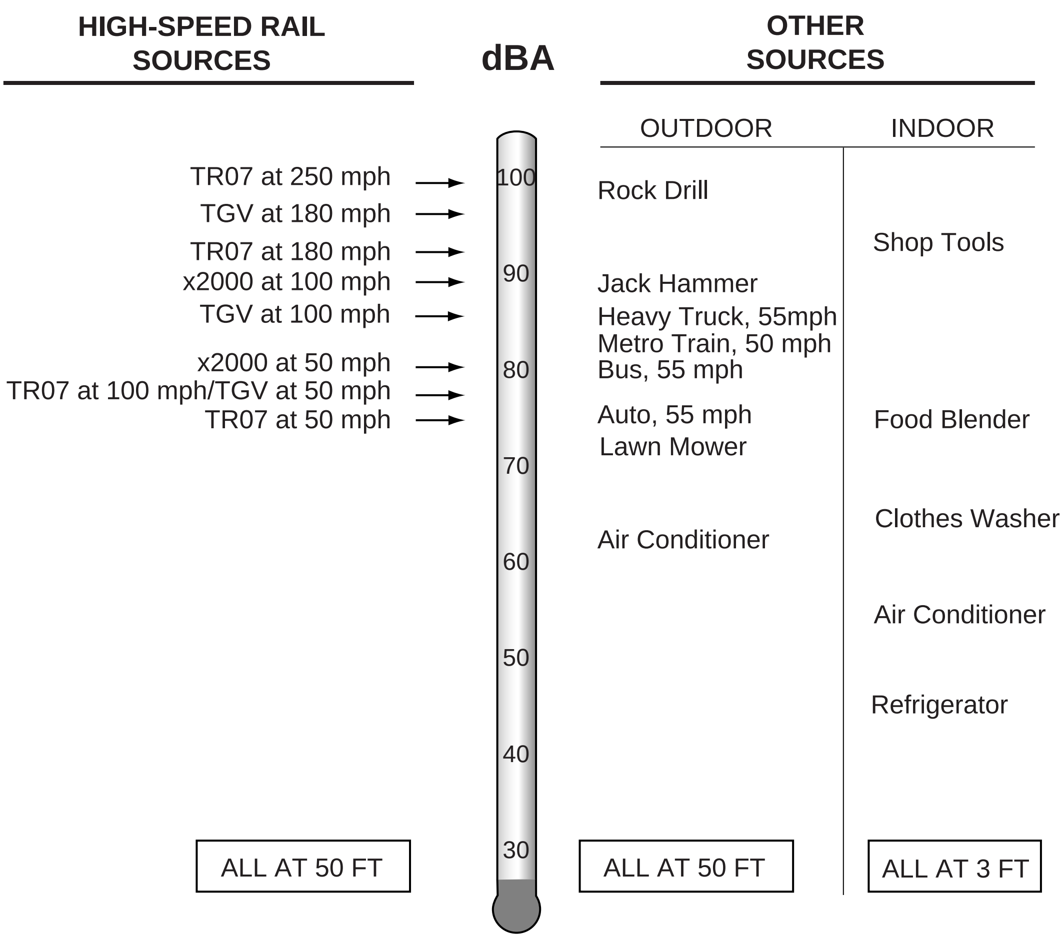

Figure 2-2 Typical A-Weighted Sound Levels

As shown in Figure 2-2, typical A-weighted sound levels range from the 40s to the 90s, where 40 is very quiet and 90 is very loud. The scale in the figure is labeled "dBA" to denote the way A-weighted sound levels are typically written. The letters "dB" stand for "decibels" and refer to the general strength of the noise. The letter "A" indicates that the sound has been filtered to reduce the strength of very low and very high-frequency sounds, much as the human ear does. Without this A-weighting, noise monitoring equipment would respond to events people cannot hear, such as high-frequency dog whistles and low-frequency seismic disturbances. On the average, each A-weighted sound level increase of 10 decibels corresponds to an approximate doubling of subjective loudness. Definitions of acoustical terms are given in Appendix D. Additional information on noise and its measurement can be obtained from textbooks and handbooks on acoustics.

2.1.1 Standard U.S. Noise Descriptors

This manual uses the following single-number descriptors, all based on the A-weighted sound level as the fundamental unit, for environmental noise measurements, computations, and assessment:

The **Maximum Level (L_{max})** during a single noise event. There are two standard ways of obtaining the L_{max}, one using the "fast" response setting on the sound level meter, or $L_{max,f}$ (obtained by using a 0.125 second averaging time), and the other using the "slow" setting, or $L_{max,slow}$ (obtained by using a 1 second averaging time). $L_{max,fast}$ can occur arbitrarily and is usually caused by a single component on a moving train, often a defective component such as a flat spot on a wheel. As a result, inspectors from the Federal Railroad Administration use $L_{max,fast}$ to identify excessively noisy locomotives and rail cars during enforcement of Railroad Noise Emission Compliance Regulations.[3] $L_{max,slow}$, with its greater averaging time, tends to de-emphasize the effects of non-representative impacts and impulses and is generally better correlated with the Sound Exposure Level (SEL), defined below, which is the basis of impact assessment. Thus, $L_{max,slow}$ is typically used for modeling train noise mathematically. In general, however, the L_{max} descriptor in either form is not recommended for noise impact assessment. Because it is used in vehicle-noise specifications and commonly measured for individual vehicles, equations are included in Appendix C to convert between $L_{max,slow}$ and the cumulative descriptors described below.

The **Sound Exposure Level (SEL)** describes a receiver's cumulative noise exposure from a single noise event. It is represented by the total A-weighted sound energy during the event, normalized to a one-second interval. It is the primary descriptor of high-speed rail vehicle noise emissions and an intermediate value in the calculation of both L_{eq} and L_{dn} (defined below).

The **Hourly Equivalent Sound Level [L_{eq}(h)]** describes a receiver's cumulative noise exposure from all events over a one-hour period. The underlying metric for calculating L_{eq}(h) is SEL. L_{eq}(h) is used in this manual to assess noise for non-residential land uses. For assessment, L_{eq} is computed for the loudest operating hour during the hours of noise-sensitive activity.

The **Day-Night Sound Level (L_{dn} or DNL)** describes a receiver's cumulative noise exposure from all events over a 24-hour period. The basic unit used in calculating L_{dn} is the L_{eq}(h) for each one-

[3] U.S. Department of Transportation, Federal Railroad Administration, "Railroad Noise Emission Compliance Regulations," Final Rule, 48 Federal Register 56756 - 56761; December 23, 1983 (23 Code of Federal Regulations 210).

hour period. It may be thought of as a noise exposure, totaled after increasing all nighttime A-Levels (between 10 p.m. and 7 a.m.) by 10 decibels. Every noise event during the 24-hour period increases this exposure, louder events more than quieter events, and events that are of longer duration more than briefer events. In this manual, L_{dn} is used to assess noise for residential land uses. Typical community L_{dn}s range from about 50 to 70 dBA, where 50 represents a quiet noise environment and 70 is a noisy one.

Detailed definitions and mathematical representations of all of these noise descriptors are presented in Appendix A.

2.1.2 Other Noise Descriptors

Noise from high-speed rail systems is often measured, reported or referred to in terms of other descriptors used primarily in Europe and Japan. These descriptors are slightly different in their mathematical definitions from the U.S. descriptors listed above. To avoid confusion with the descriptors used in this manual, Table 2-1 provides a partial list of these descriptors and a brief definition of each. Mathematical definitions to assist the user to translate data to the descriptors in this manual are provided in Appendix A.

Table 2-1   Summary of International Rail Noise Descriptors

Metric	Abbreviation(s)	Country	Definition
A-weighted Passby Level	$L_{aeq,P}$ or $L_{p,p}$	Germany, France	Equivalent A-weighted sound-pressure level, energy-averaged over the time of passby (train length).
	L_{max}(mean)	Scandinavia	
One-Hour L_{eq}	$L_{aeq,1h}$ or $L_{p,1h}$	Germany, France	Sound-pressure level, energy-averaged over one hour.
Average A-weighted Maximum Level	L_{Amax}	Japan	Power-averaged "slow" maximum level ($L_{max,s}$) of 20 consecutive train passbys.
Sound Exposure Level	L_{AE}	Japan	Power-averaged value of sound exposure within 10 dB of L_{Amax}, sampled at a time interval of 5/3 sec.

2.1.3 The L_{max}-SEL Relationship

To help the reader gain a preliminary understanding of high-speed rail noise descriptors and the interrelationships among descriptors, the following discussion illustrates how SEL, the fundamental descriptor used in calculating noise exposure, relates to L_{max}. Both descriptors characterize a single noise event; however, they do not always correlate with each other.

The L_{max} for a typical high-speed train passby is identified in Figure 2-3, where time is plotted horizontally and A-weighted sound level is plotted vertically. The event shown represents a measured time signature of a TGV passby at 180 mph at 83 feet (25 meters).

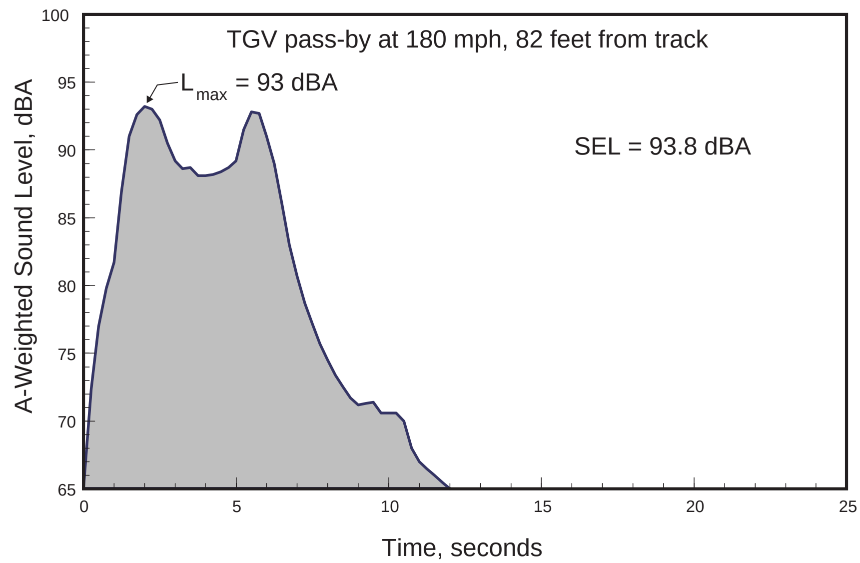

Figure 2-3 Typical High-Speed Train Passby

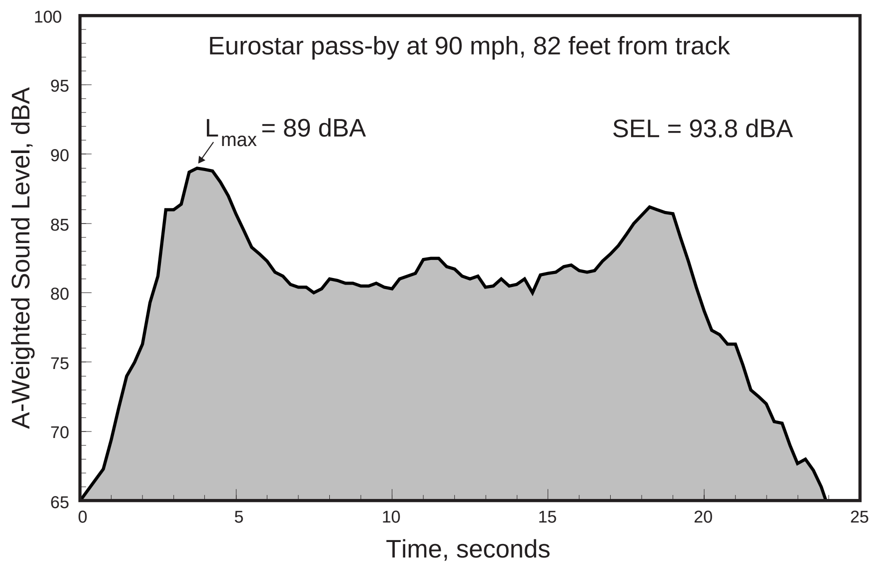

Figure 2-4 Typical Longer-Duration High-Speed Train Event

The noise exposure that occurred during a high-speed train passby, is shaded in Figure 2-3. This exposure represents the total amount of sound energy that enters the receiver's ears (or the measurement microphone) during the passby. A noise event of longer duration, a Eurostar train passby at 90 mph, is shown in Figure 2-4. For this event, the noise exposure is large due to *duration*. Since the Eurostar train is nearly two times as long as the standard TGV trains, both the added length and slower speed contribute to the increased duration of the Eurostar event. Compared with the event in Figure 2-3, the L_{max} is 4 dBA lower, but the measured SELs are the same.

The time histories in Figures 2-3 and 2-4, but with a stretched vertical scale are repeated in Figure 2-5. The stretched scale corresponds to a linear scale of sound pressure, or energy, at any moment in time. Mathematically, sound energy is proportional to 10 raised to the (L/10) power, that is, $10^{(L/10)}$. The stretched vertical scale represents noise exposure as energy exposures. Only when plotted at this stretched scale do the shaded zones properly correspond to the noise exposures that underlie the SEL. The shaded zones in the two frames have equal areas, corresponding to equal noise exposures for these two very different noise events.

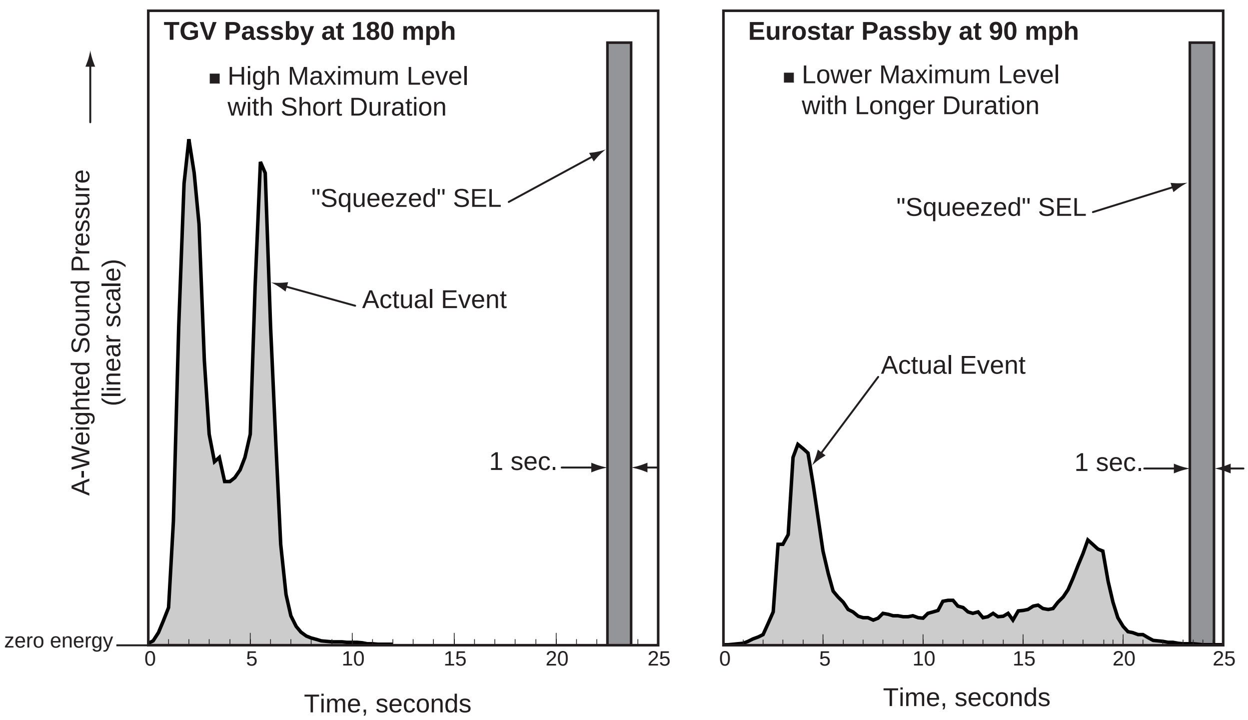

Figure 2-5 An "Energy" View of Noise Events

Each frame of the figure also contains a tall, thin shaded zone of one-second duration. This tall zone is the way to envision SELs. In the tall zone, the original shaded zone has been squeezed shorter and shorter in time, while retaining the same area. As its duration is squeezed, its height increases to keep the area constant. If a noise exposure shading is squeezed to a duration of one second, its height will then equal its SEL value; mathematically, its area is now $10^{(L/10)}$ times one second. Note that the resulting height of the squeezed zone depends both upon the L_{max} and the duration of the event – that is, upon the total area under the original, time-varying A-weighted sound level.

2.1.4 Onset Rate

An important characteristic of the noise from high-speed rail systems is the **onset rate** of the sound signature. Onset rate is the average rate of change of increasing sound pressure level in decibels per second (dB/sec) during a single noise event. The rapid approach of a high-speed train is accompanied by a sudden increase in noise for a receiver near the tracks. Researchers report that sounds of approaching vehicles carry a sense of convergence and cause greater annoyance than receding sounds.[4] Moreover, sounds with fast onset rates are more annoying than sounds with less rapid variation or steady noise with the same maximum noise level.[5] Research by the U.S. Air Force on the effect of onset rate on aircraft noise annoyance shows that people are increasingly annoyed by sudden sounds with onset rates greater than about 15 dB per second (dB/sec), as described more fully in Appendix A.[6,7] Onset rates of greater than 15 dB/sec occur for receivers within 60 feet of a 150 mph train, and occur at greater distances for trains at higher speeds. Measured onset rates for a steel wheel train (ICE) and a maglev train (TR 07) are shown plotted for the ratio of speed to distance in Figure 2-6. The plot shows that onset rate:

- increases as speed increases for a given distance, and
- decreases as distance increases for a given speed.

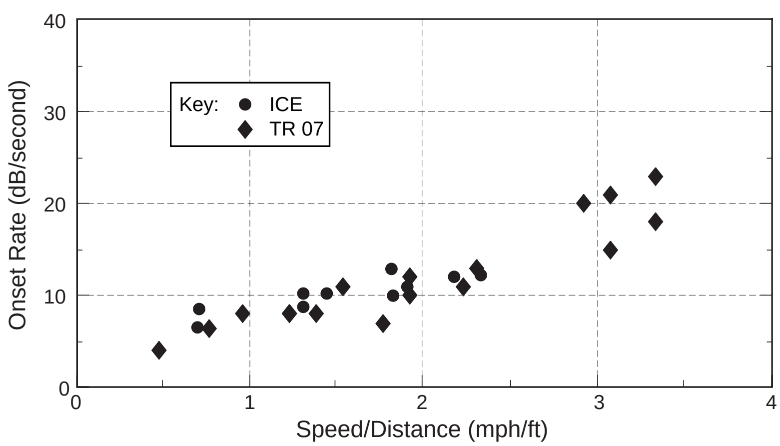

Figure 2-6 Measured High-Speed Rail Onset Rates

[4]G. Rosinger, D. W. Nixon and H.E. von Gierke, "Quantification of the Noisiness of 'Approaching' and 'Receding' Sounds," J. Acoust. Soc. Am., 48, pp. 843-853, October 1970.

[5]K. Plotkin, L.C. Sutherland, J.A. Molino, "Environmental Noise Assessment for Military Aircraft Training Routes: Volume 2: Recommended Noise Metric." Wyle Laboratories Report WR 86-21 prepared for Wright-Patterson Air Force Base AAMRL/BBE, April 1987.

[6]K.J. Plotkin, K. W. Bradley, J.A. Molino, K.G. Helbing, D.A. Fisher. "The Effect of Onset Rate on Aircraft Noise Annoyance, Vol. 1: Laboratory Experiments," US Air Force Systems Command, Report Number AL-TR-1992-0093, May 1992.

[7]E. Stusnick, K.A. Bradley, J.A. Molino, and G. deMiranda. "The Effect of Onset Rate on Aircraft Noise Annoyance, Vol. 2: Rented Home Experiment." US Air Force Materiel Command, Report Number AL/OE-TR-1993-0170, October 1992.

Although the measured onset rates in Figure 2-6 do not exceed about 25 dB/sec at normal measurement distances, actual onset rates can rise to greater values close to the tracks. When onset rates exceed about 30 dB/sec people tend to be startled, or surprised by the sudden onset of the sound. **Startle** as an added factor in annoyance is discussed in Appendix A-4. The onset rate of 30 dB/sec is used as the basis for establishing distances within which startle is likely to occur and serves as added information in the impact assessment methods presented in Chapters 4 and 5.

2.2 SOURCES OF HIGH-SPEED RAIL NOISE

The total wayside noise generated by a high-speed train passby consists of several individual noise-generating mechanisms, each with its own characteristics of source location, strength, frequency content, directivity, and speed dependence. These noise sources can be generalized into three major regimes:[8]

Regime I. propulsion or machinery noise,

Regime II. mechanical noise resulting from wheel/rail interactions and/or guideway vibrations, and

Regime III. aerodynamic noise resulting from airflow moving past the train.

For a conventional train with a maximum speed of up to about 125 mph, propulsion and mechanical noise are sufficient to describe the total wayside noise. The aerodynamic noise component begins to be an important factor when the train speed exceeds about 160 mph.

The significance of these different regimes is that, for a given train, there are three distinct speed ranges in which only one sound source dominates the total noise level. The dependence of the A-weighted sound level on vehicle speed (S) for a typical high-speed train is illustrated in Figure 2-7. A qualitative indication of the maximum sound level during a passby is plotted vertically in this figure. The three speed regimes are labeled "I," "II," and "III," each corresponding to the dominant sound source in the regime, or propulsion, mechanical, and aerodynamic noise, respectively. The speed at which the dominant sound source changes from one to another is called an acoustical transition speed (v_t). The transition from propulsion noise to mechanical noise occurs at the lower acoustical transition speed (v_{t1}), and the transition from mechanical to aerodynamic noise occurs at the upper acoustical transition speed (v_{t2}).

The various noise sources for a steel-wheeled high-speed tracked system and maglev system are illustrated in Figures 2-8 and 2-9 respectively. These sources differ in where they originate on the train and in what frequency range they dominate.

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[8] B. Barsikow and B. Müller, “Wayside noise generated by the German high-speed transport systems, ICE and Transrapid,” 72nd Annual Meeting of the Transportation Research Board, Washington, D.C., 1993.

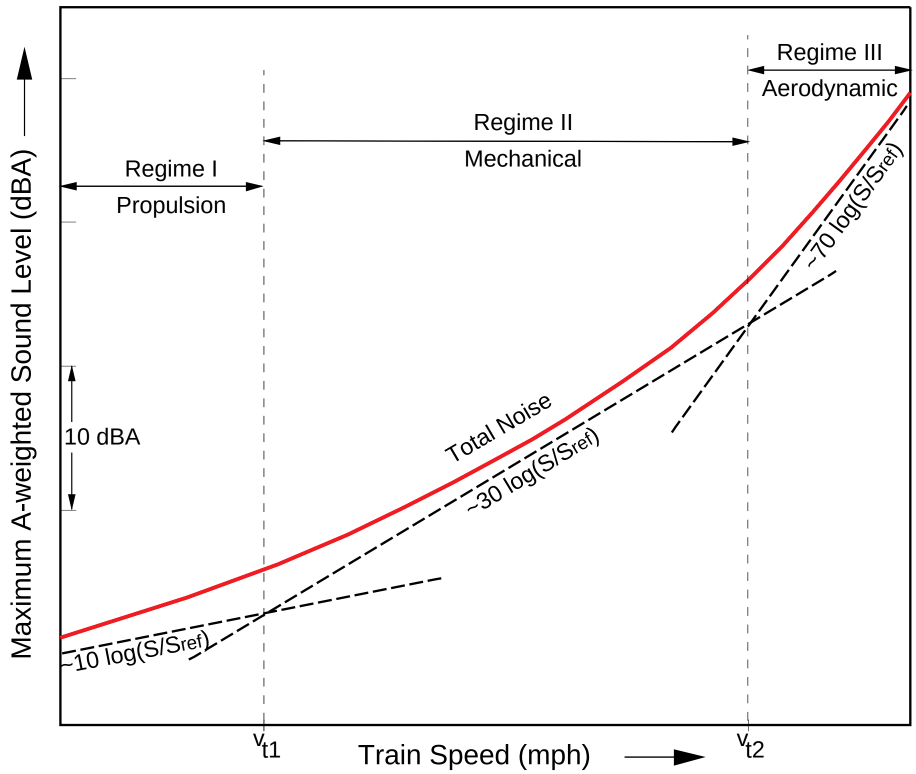

Figure 2-7 Generalized Sound Level Dependence on Speed

2.2.1 Regime I: Propulsion Sources

Steel-Wheeled Trains. At low speeds, Regime I, propulsion mechanisms, or machinery and auxiliary equipment that provide power to the train are the predominant sound sources. Most high-speed trains are electrically powered; the propulsion noise sources are, depending on the technology, associated with electric traction motors or electromagnets, control units, and associated cooling fans (see Figure 2-8). Fans can be a major source of noise; on conventional steel-wheeled trains fans are usually located near the top of the power units, about 10 feet above the rails. Fan noise tends to dominate the noise spectrum in the frequency bands near 1000 Hz. External cooling fan noise tends to be constant with respect to train speed, which makes fans the dominant noise when a train is stopped in a station.

Maglev Trains. Noise from the propulsion magnets in a maglev system is a result of induced vibration from magnetic forces. One source of vibration is oscillating magnetostriction, which also causes the characteristic hum sometimes heard from electrical transformers and which is likely to be tonal in character (see Figure 2-9). Sound at the magnetic pole-passing frequency is another effect of magnetic traction; the interaction of the moving vehicle and the stationary magnetic poles at a uniform spacing causes a tonal sound that varies uniformly with velocity. These forces are located at the magnet gaps between the vehicle and the guideway. Propulsion noise in general has a relatively weak speed dependence, typically following a relationship of ten times the logarithm of speed.

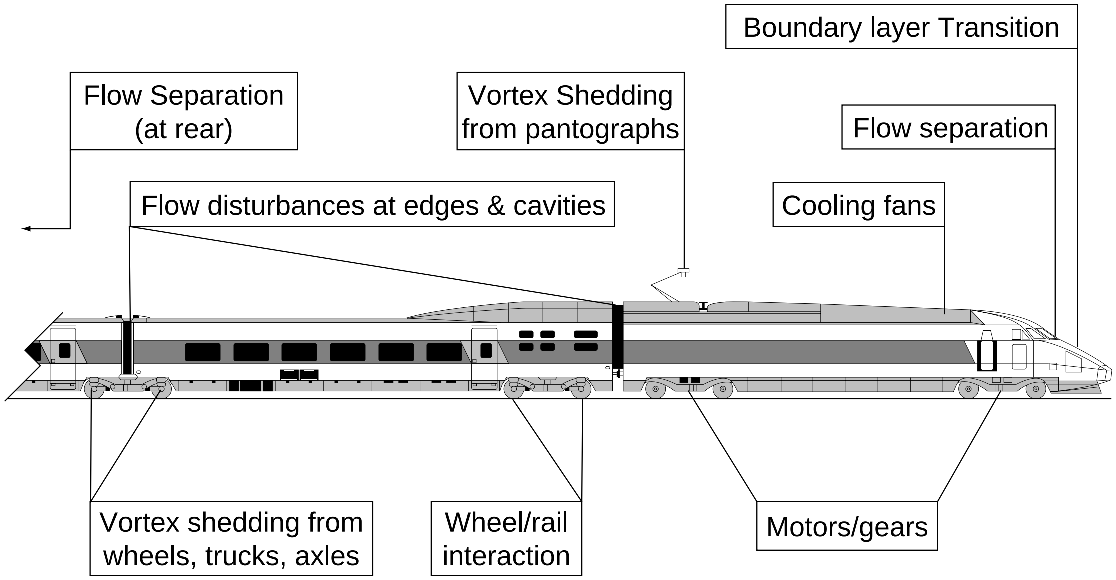

Figure 2-8 Noise Sources on a Steel-Wheeled High-Speed Rail System

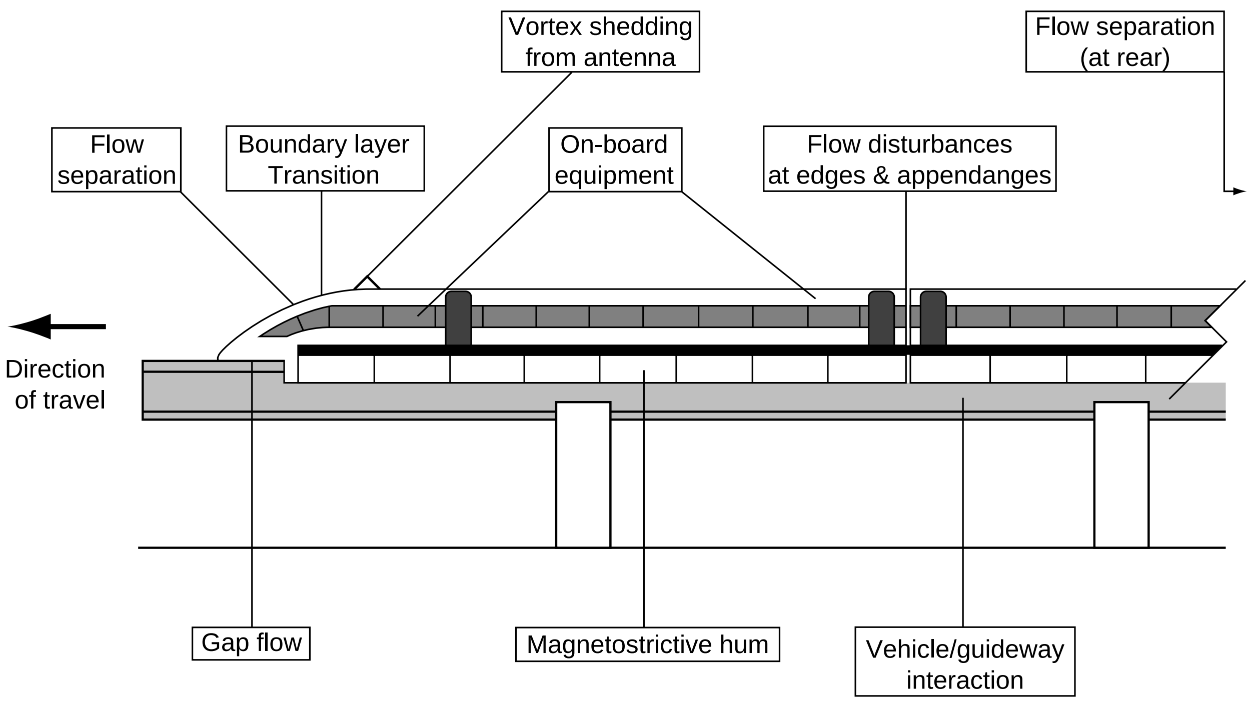

Figure 2-9 Noise Sources on a Maglev System

2.2.2 Regime II: Mechanical/Structural Sources

Steel-Wheeled Trains. The effects of wheel-rail interaction of high-speed trains, guideway structural vibrations, and vehicle-body vibrations fall into the category of mechanical noise sources. These sources tend to dominate the total noise level at intermediate speeds (Regime II), and cover the widest of the three speed regimes. For steel-wheeled trains, wheel-rail interaction is the source of the rolling noise radiated by steel wheels and rails caused by small roughness elements in the running surfaces. This noise source is close to the trackbed with an effective height of about 2 feet above the rails. The spectrum for rolling noise peaks in the 2 kHz to 4 kHz frequency range, and it increases more rapidly with speed than does propulsion noise, typically following the relationship of 30 times the logarithm of train speed. Wheel-rail noise typically dominates the A-weighted sound level at speeds up to about 160 mph.

Maglev Trains. Maglev technology is not free from mechanical/structural noise sources despite the lack of physical contact with the guideway. The maglev analogies to wheel-rail noise from a steel-wheeled train are noise from wheels rolling on guideway support surfaces at low speeds for electrodynamic (EDS) systems, which require forward motion up to a certain speed before lift can occur, and noise from magnetic pole-passing. Sound also is radiated by guideway vibrations and vehicle body vibrations. Both of these sources tend to radiate sounds at relatively low acoustical frequencies; fundamental resonance frequencies of guideway support beams are generally below 10 Hz, with radiation from box beam panels up to about 80 Hz. Vehicle body vibrations depend on the details of body panel construction; they can result in substantial sound radiation throughout the audible range. For maglev systems, the combination of all mechanical sources results in an increase of noise approximately 30 times the logarithm of speed.

2.2.3 Regime III: Aerodynamic Sources

Propulsion and rolling noise are generally sufficient to describe the total noise up to speeds of about 160 mph for steel-wheeled trains. Above this speed, however, aerodynamic noise sources tend to dominate the radiated noise levels. These sources begin to generate significant noise at speeds of about 180 mph, depending on the magnitude of the mechanical/structural noise. For maglev, this transition occurs at a lower speed due to low levels of mechanical noise.

Steel-Wheeled Trains. Aerodynamic noise is generated from high-velocity airflow over the train. For a conventional steel-wheeled train, the components of aerodynamic noise are generated by unsteady flow separations at the front and rear of the train and on structural elements of the train (mainly in the regions encompassing the trucks, the pantograph, inter-coach gaps, and discontinuities along the surface), and a turbulent boundary layer generated over the entire surface of the train.

Maglev Trains. For a maglev vehicle, aerodynamic noise sources include the flow separation on the front and rear ends, vortex shedding from the antennae, flow interactions in the gap between the vehicle and guideway, the wake generated at the trailing end, and the turbulent boundary layer.

Aerodynamic sources generally radiate sound in the frequency bands below 500 Hz, generally described as a rumbling sound. Aerodynamic noise level increases with train speed much more rapidly than does propulsion or rolling noise, with typical governing relationships of 60 to 70 times the logarithm of speed.

2.3 SOUND PROPAGATION PATH

This section contains a qualitative overview of noise-path characteristics from source to receiver, including attenuation along these paths. Sound paths from source to receiver are predominantly air-borne. Along these paths, sound reduces with distance due to (1) **divergence**, (2) **absorption/diffusion**, and (3) **shielding**. The general equation for the prediction of the A-weighted sound level at various distances from the track can be expressed as follows:

$$L_A = L_A(ref) + C_d + C_a + C_g + C_b$$

where:
- $L_A(ref)$ = a known A-weighted sound level at some reference distance *ref* from the source
- C_d = adjustment factor for attenuation due to divergence
- C_a = adjustment factor for excess attenuation due to atmospheric absorption
- C_g = adjustment factor for excess attenuation from ground absorption
- C_b = adjustment factor for excess attenuation due to obstacles such as barriers, berms, and buildings.

In nearly all cases, the adjustment factors are negative numbers due to the nature of the reference conditions. Each of these adjustment factors are discussed in Sections 2.3.1-2.3.3 in terms of their mechanisms of sound attenuation. Specific equations for computing noise-level attenuations along source-receiver paths are presented in Chapters 4 and 5. Sometimes a portion of the source-to-receiver path is not through the air, but rather through the ground or through structural components of the receiver's building. Ground-borne and structure-borne noise propagation are discussed in Chapter 6.

2.3.1 Divergence

Sound levels naturally attenuate with distance. Such attenuation, technically called "divergence," depends upon source configuration and source-emission characteristics. Divergence is shown graphically for point sources and line sources separately in terms of how they attenuate with distance in Figure 2-10. The divergence adjustment factor, C_d, for the receiver is plotted vertically relative to the sound level 50 feet from the source. As shown, the sound level attenuates with increasing distance due to the geometric spreading of sound energy.

For sources grouped closely together (called point sources), attenuation with distance is large: 6 decibels per doubling of distance. Most individual noise sources on a moving high-speed rail vehicle radiate sound as point sources. When many point sources are arrayed in a line, all radiating sound at the same time so any one source is not distinguishable, the arrangement is called a line source. For line sources, divergence with distance is less: 3 decibels per doubling of distance for L_{eq} and L_{dn}, and 3 to 6 decibels per doubling of distance for L_{max}. A train passing along a track or guideway can be considered a line source. In Figure 2-10, the line source curve separates into three separate lines for L_{max}, with the point of departure depending on the length of the line source. For example, close to a short train, it behaves like a line source; far away, it behaves as a point source. The curves shown in Figure 2-10 are for illustrative purposes only, and the exact equations for these curves given Chapter 5 should be used for quantitative analyses.

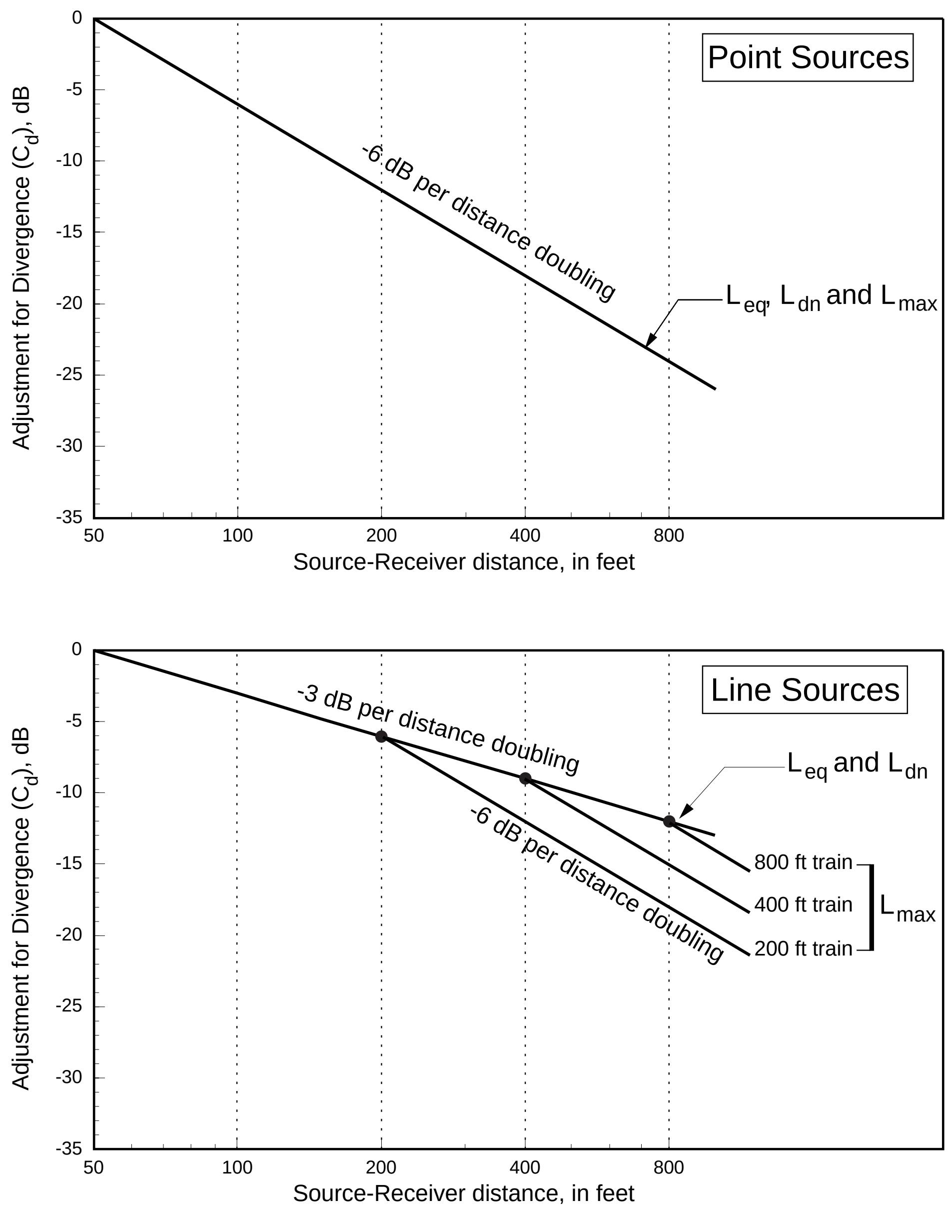

Figure 2-10 Attenuation due to Distance (Divergence)

Some sound sources, such as warning bells, radiate sound energy nearly uniformly in all directions. These are called nondirectional, or monopole, sources. For train noise, however, the rolling noise from wheel-rail interactions, as well as some types of aerodynamic noise, is complicated because the sources do not radiate sound equally well in all directions. This unequal radiation is known as **source directivity**, which is a measure of the variation in a source's radiation with direction. Studies have shown that wheel-rail noise can be modeled by representing the source as a line source (or continuous row of point sources) with dipole directivity.[9] A dipole radiation pattern has also been observed in the turbulent boundary layer near the sides of a train.[10] Typically, a dipole source radiates a directivity pattern such that the sound pressure is proportional to the cosine of the angle between the source orientation and the receiver. Consequently, wheel-rail noise is propagated more efficiently to either side of a moving train than in front, above or behind it.

2.3.2 Absorption/Diffusion

In addition to attenuating because of geometric spreading of the sound energy, sound levels are further attenuated when sound paths lie close to absorptive or "soft" ground, such as freshly plowed or vegetation-covered areas. This additional attenuation, which can be 5 decibels or more within a few hundred feet is illustrated graphically in Figure 2-11. In this figure the adjustment factor, C_g, is plotted vertically as a function of distance. At very large distances, wind and temperature gradients can alter the ground attenuation shown here; such variable atmospheric effects generally influence noise levels well beyond the range of typical railway noise impact and are not included in this manual. Equations for the curves in Figure 2-11 are presented in Chapter 5.

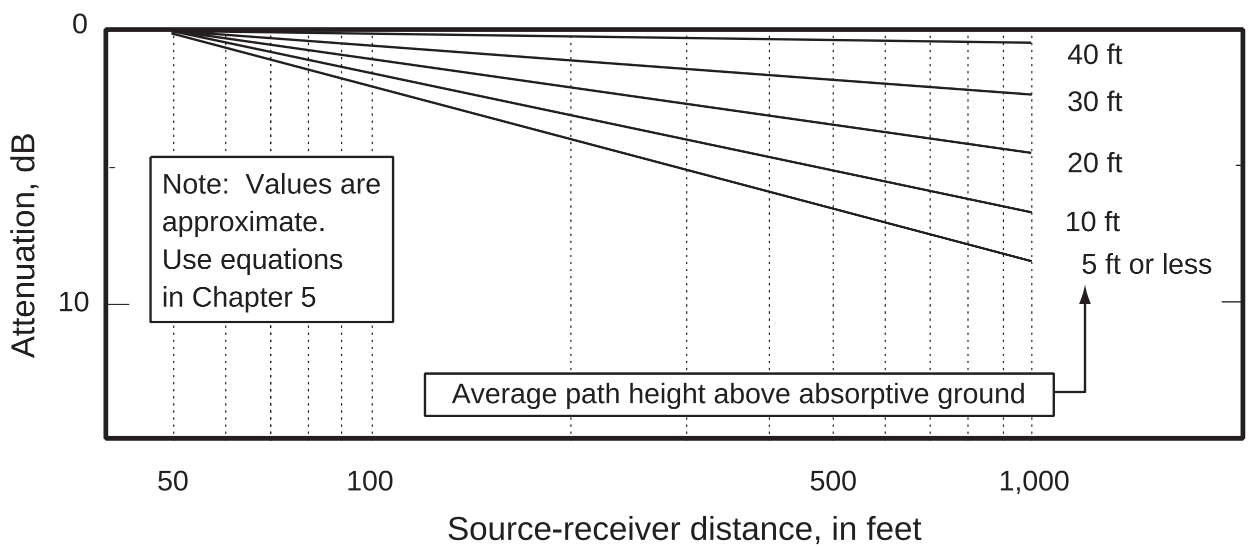

Figure 2-11 Attenuation due to Soft (Sound-Absorptive) Ground

[9]E.J. Rathe, "Railway noise propagation," J. Sound Vib. 51, 371-388 (1977).

[10]W.F. King, "On the boundary layer contribution to wayside noise generated by high-speed tracked vehicles," Inter-Noise '94 Proceedings (1994), pp.175-180.

2.3.3 Shielding

Sound paths are sometimes interrupted by noise barriers, by terrain, by rows of buildings, or by vegetation. Noise barriers, usually the most effective means of mitigating noise in sensitive areas, are the most important of these path interruptions. A noise barrier reduces sound levels at a receiver by breaking the direct path between source and receiver with a solid wall; vegetation, in contrast, hides the source but does not reduce sound levels significantly. Sound energy reaches the receiver only by bending (diffracting) over the top of the barrier, as shown in Figure 2-12. This diffraction reduces the sound level at the receiver.

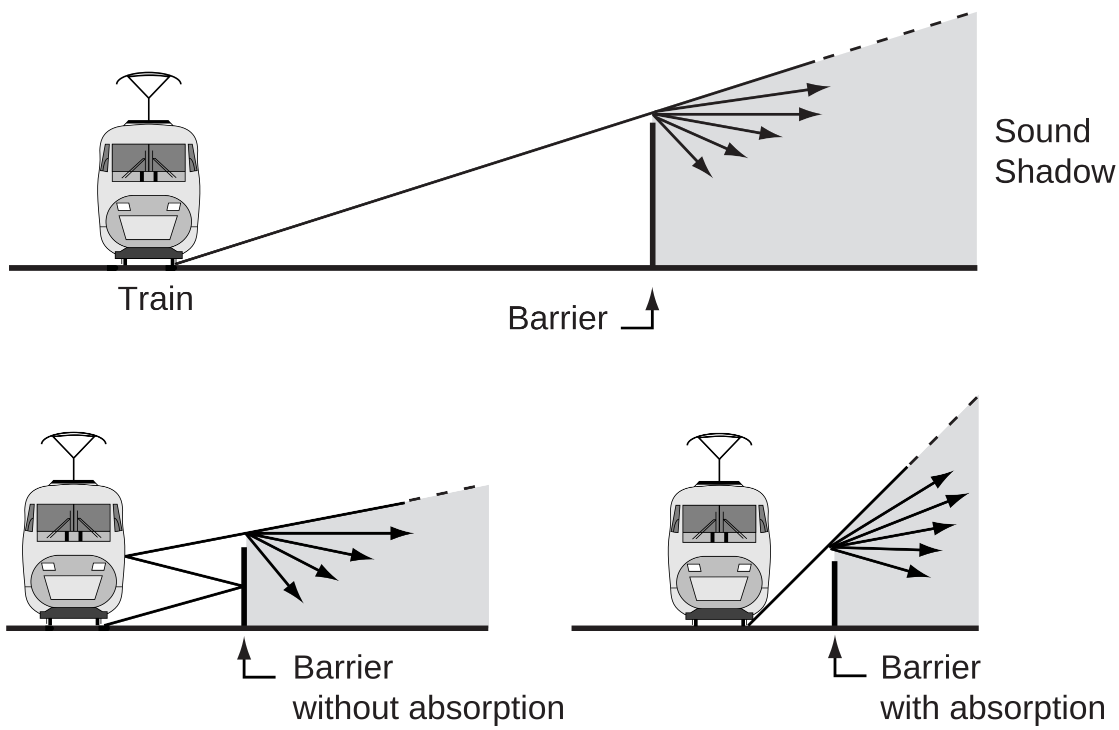

Figure 2-12 Noise Barrier Geometry

Noise barriers for transportation systems typically attenuate noise at the receiver by 5 to 15 dBA (which corresponds to an adjustment factor C_b range of -5 to -15 dBA), depending upon receiver and source height, barrier height, length, and distance from both source and receiver. The attenuation of noise by a barrier also is frequency dependent, i.e., all other factors being the same, the higher the frequency of the noise, the greater the barrier attenuation. As discussed in Section 2.2, the peak frequencies and source heights of high-speed rail noise vary according to the dominant noise source in a particular speed regime. In general, aerodynamic noise has lower peak frequencies than does wheel-rail noise, which means that a barrier is less effective at attenuating aerodynamic noise. In addition, aerodynamic noise sources tend to be located higher up on the train than wheel-rail noise sources. As a result, a noise barrier high enough to shield aerodynamic noise will be relatively expensive compared to a barrier for controlling wheel-rail noise, since it must extend 15 feet or more above the top of rail. For operating speeds up to about 160 mph, a barrier high enough to shield wheel-rail and other lower car body sound sources would normally provide sufficient sound attenuation.

Barriers on structure, very close to the source, provide less attenuation than predicted using standard barrier attenuation formulae, due to reverberation (multiple reflections) between the barrier and the body of the train. This reverberation can be offset by increased barrier height, which is easy to obtain for such close barriers, and/or the use of acoustically absorptive material on the source side of the barrier. These concepts are illustrated in Figure 2-12. Acoustical absorption is included as a mitigation option in Chapter 5. Equations for barrier attenuation, as well as equations for other sound-path interruptions, also are presented in Chapter 5.

2.4 MATHEMATICAL MODEL OF HIGH-SPEED RAIL NOISE

The development of the high-speed rail noise prediction model consists of two distinct parts: (1) identification of sources, and (2) modeling of the outdoor sound propagation. Part (1) involves the identification and localization of sound sources specific to high-speed rail, and is based solely on empirical data. Section 2.4.1 presents an overview of the available data used to quantify these sources. Part (2) involves the application of sound propagation theory to account for characteristics of the noise path. Section 2.4.2 provides a summary of the mathematical models used to predict sound levels at specific locations.

2.4.1 Identification of Sources

Most of the data used to develop the high-speed rail noise model are taken from measurements of revenue service high-speed train operations in Europe.[11] These measurements of electrically powered trains include the TGV and Eurostar trains in France, the X2000 tilt train in Sweden, and the Pendolino tilt train in Italy. The purpose of the measurement program is to document wayside noise levels from representative European high-speed trainsets, with the specific objective of developing a prediction model for high-speed rail noise. In addition, an existing database of noise measurements from the U.S. Northeast Corridor (NEC) Electrification Project [12], the National Maglev Initiative (NMI) Project [13], and various other sources, provide supplementary data on ICE (Germany), TGV, X2000, RTL-2 (gas-turbine powered), and TR07 (German maglev trainsets).

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[11]Measurements were conducted by Harris Miller Miller & Hanson Inc., in April and May, 1995, as part of the methodology development effort for this manual.

[12]U.S. Department of Transportation, Federal Railroad Administration, Northeast Corridor Improvement Project Electrification -New Haven,CT to Boston, MA: Final Environmental Impact Statement/Report, Volume II: Technical Studies , Chapter 4. Noise and Vibration. DOT/FRA/RDV-94/01-B, DOT-VNTSC-FRA-94-6, Final Report October 1994.

[13]U.S. Department of Transportation, Federal Railroad Administration, Noise from High Speed Maglev Systems, DOT/FRA/NMI-92/18, January 1993.

As an overview of the available data, measured noise levels from the various high-speed trainsets are plotted over a range of speeds in Figures 2-13 and 2-14. A graph of $L_{max,slow}$ as a function of train speed, normalized to a reference distance of 100 feet is shown in Figure 2-13. Figure 2-14 shows the noise level plotted in terms of SEL, with the data normalized to a reference distance of 100 feet and a reference train length of 740 feet. Data from the following test programs are represented in these figures:

- Revenue service operations in Europe. Data from the European measurement program conducted in France, Italy and Sweden referred to above are plotted as individual data points in the graphs. Each data point represents a large quantity of data averaged over similar speed events. Sites were selected to cover a relatively wide speed range. They include operations of the TGV and Eurostar in France, Pendolino in Italy, and X2000 in Sweden.
- Maglev test track in Germany. TR07 noise curve is based on regression analysis of data obtained from tests on a prototype maglev vehicle (TransRapid TR07) at the maglev test track in Emsland, Germany.
- Trainset demonstrations on NEC. Curves of noise level versus speed generated by the noise model recently developed as part of the NEC Electrification Project are included.[14] These curves are based on measurements conducted on the Northeast Corridor as part of demonstration testing of several newer-technology trainsets (including the German ICE, Swedish X2000, and the U.S./French RTL-2 Turboliner) in the U.S. The curves are plotted up to the actual maximum speed obtained for each trainset during testing, even though the maximum allowable speed may be higher.

The results in Figures 2-13 and 2-14 indicate that the European steel-wheeled train measurement data generally fall within the range of the train noise curves developed for the NEC Project. The results also suggest that:

- The TGV trains tested in Europe have noise emissions similar to the ICE and RTL-2 trains tested in the U.S.
- Wayside noise levels for the X2000 and Pendolino trains averaged about 5 decibels higher than other trains measured, with noise emissions similar to the X2000 train tested in the U.S.
- Data for the Eurostar trains showed the greatest variation, with noise levels scattered over the range for other trains.

Maglev noise levels are consistently low relative to the steel-wheeled trains, but it is clear that as speeds reach the upper limits there is less difference between the steel-wheeled and maglev technologies in the level of noise generated as the aerodynamic component becomes significant.

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[14]Because the NEC noise models were developed with less detailed consideration of noise subsources and propagation effects, they do not necessarily yield identical results as computed using the more updated models presented in Chapters 4 and 5 of this manual.

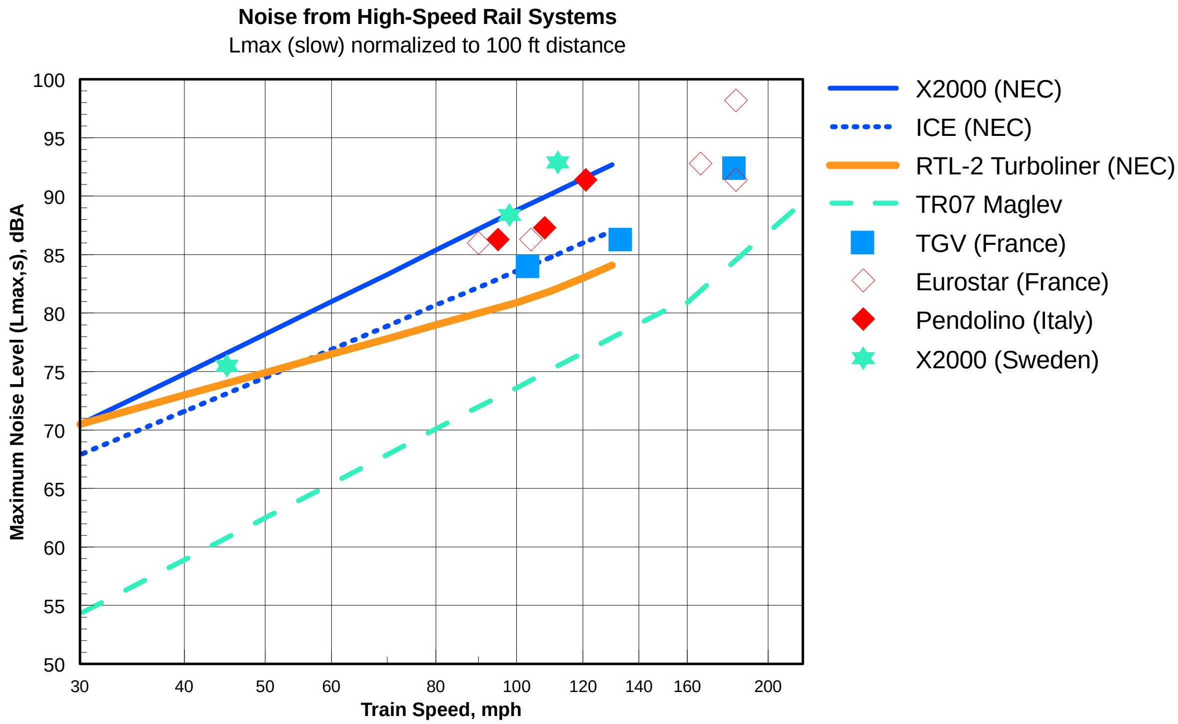

Figure 2-13 Measured Values of $L_{max,s}$ vs Speed from High-Speed Rail Systems

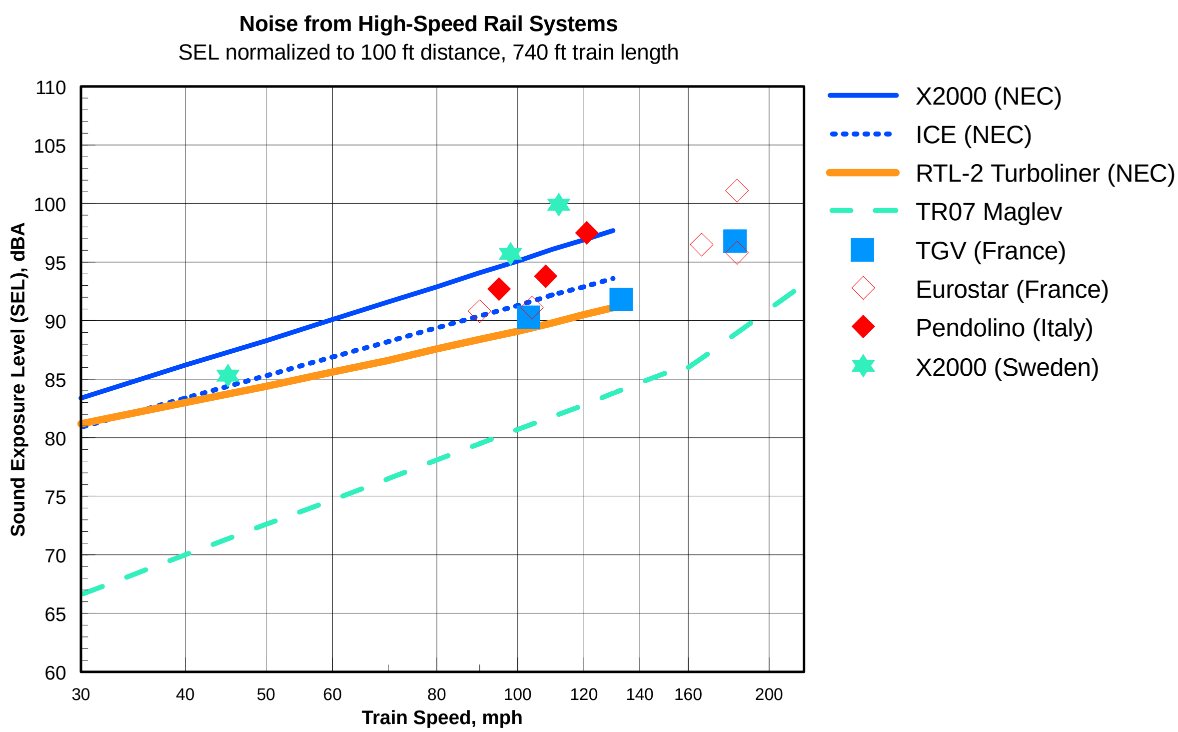

Figure 2-14 Measured Values of SEL vs Speed from High-Speed Rail Systems

2.4.2 Basic Equations

The general approach used to model noise from high-speed trains considers each noise source from a train passby separately as a moving line source of given length, height, speed dependence, and directivity pattern. The standard model for noise from wheel-rail interactions is an incoherent dipole line source.[9] Most other sources, such as propulsion and aeroacoustic mechanisms, can be modeled as having simple monopole directivity.[15,16]

Since the noise impact criteria are based on noise exposure metrics L_{eq} and L_{dn}, the noise computations are based on a reference SEL for each source corresponding to a set of reference operating conditions. Since L_{max} is often the quantity that is measured or provided in vehicle noise specifications, it is important to understand the relationship between L_{max} and SEL. The following equations based on Rathe's model[9] can be used to relate SEL to L_{max} under reference conditions:

$$SEL = L_{max} + 10\log\left(\frac{len}{v}\right) - 10\log\{2\alpha + \sin(2\alpha)\} + 3.3 \qquad \text{for dipole sources}$$

$$SEL = L_{max} + 10\log\left(\frac{len}{v}\right) - 10\log(2\alpha) + 3.3 \qquad \text{for monopole sources}$$

where:

L_{max} = reference $L_{max,s}$ under reference conditions (v_{ref}, y_{ref}), dBA,

len = reference source length, feet,

v = reference train speed, mph,

$\alpha = \tan^{-1}\left(\frac{len}{2y}\right)$, radians, and

y = reference observer distance from track centerline, feet.

Reference conditions are given in tables in Chapters 4 and 5. The following equation is then used to adjust a reference SEL to other operating conditions at the reference distance *y*:

$$SEL = SEL_{ref} + 10\log\left(\frac{len}{len_{ref}}\right) + K\log\left(\frac{v}{v_{ref}}\right)$$

[15] The radiating parts of aerodynamic noise such as the pantograph and the turbulent boundary layer near the wall can originate from dipole-like sources. However, because of the turbulent nature of the sound-generating mechanisms, the directions of the axes of dipoles are likely to vary in time and position, resulting in a more or less randomly radiating chaos of fluctuating dipoles. Thus, the global directivity pattern of a train is more appropriately modeled as a monopole, even though the sources may be dipoles locally.

[16] J.D. van der Toorn, H. Hendriks, T.C. van den Dool, "Measuring TGV source strength with SYNTACAN," J. Sound Vib. 193(1), 1996, p. 113-121.

where:

$$len = \text{source length, feet,}$$
$$K = \text{speed coefficient, and}$$
$$v = \text{train speed, mph.}$$

SEL and L_{max} are descriptors of noise levels from a single train passby. The following equations are used to predict noise exposure in terms of the cumulative metrics $L_{eq}(h)$ and L_{dn}, and to adjust for divergence and the effects of the propagation path:

$$L_{eq}(h) = SEL + 10\log(V) + C_d + C_g + C_b - 35.6$$

$$L_{dn} = 10\log\left[15\times 10^{\left(L_{eq}(day)/10\right)} + 9\times 10^{\left(L_{eq}(night)+10/10\right)}\right] - 13.8$$

where:

V = hourly volume of train traffic, in trains per hour

C_d = correction for divergence (distance attenuation), dB

C_g = correction for ground attenuation, dB

C_b = correction for excess shielding due to barriers or berms, dB

$L_{eq}(day)$ = daytime L_{eq}, or energy-average $L_{eq}(h)$ during daytime hours (7 a.m. to 10 p.m.)

$L_{eq}(night)$ = nighttime L_{eq}, or energy-average $L_{eq}(h)$ during nighttime hours (10 p.m. to 7 a.m.)

Methods for calculating the correction factors C_d, C_g, and C_s are based on source type, receiver distance, and cross-sectional geometry are presented in Chapters 4 and 5.

Chapter 3

NOISE IMPACT CRITERIA

The criteria used in evaluating noise impacts from high-speed rail are based on maintaining a noise environment considered acceptable for land uses where noise may have an effect. These criteria take into account the unusual noise characteristics of high-speed rail operations, including the effects of startle on humans, livestock, and wildlife to the extent that these effects are known.

The noise impact criteria for high-speed rail facilities are presented in Section 3.1. These criteria are adapted from criteria developed by the Federal Transit Administration for rail noise sources operating on fixed guideways or at fixed facilities.[1] The criterion for the onset of **impact** varies according to the existing noise level and the predicted project noise level, and it is determined by the minimum measurable change in community reaction. The corresponding criterion for **severe impact** also varies according to the existing noise level as well as the project noise level, but it is determined by the change in community reaction between an acceptable and an unacceptable noise environment. Guidelines for the application of the criteria are included in Section 3.2, and background material on the development of the criteria is included in Appendix A.

3.1 NOISE IMPACT CRITERIA FOR HIGH SPEED RAIL PROJECTS

The noise impact criteria for high-speed rail projects are shown in graphs and tables in this section. The equations used to define these criteria are included in Appendix A. The criteria apply to high-speed rail

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[1] U.S. Department of Transportation, Federal Transit Administration. "Transit Noise and Vibration Impact Assessment," Final Report, DOT-T-95-16, April 1995.

operations as well as to fixed facilities such as storage and maintenance yards, passenger stations and terminals, parking facilities, and substations.

3.1.1 Basis of Noise Impact Criteria

The noise impact criteria for human annoyance, presented in Figure 3-1 and Table 3-1, are based on comparison of the existing outdoor noise levels and the future outdoor noise levels from a proposed high-speed rail project. They incorporate both absolute criteria, which consider activity interference caused by the high-speed rail project alone, and relative criteria, which consider annoyance due to the change in the noise environment caused by the project. These criteria were developed to apply to a wide variety of surface transportation modes, to recognize the heightened community annoyance caused by late-night or early-morning operations, and to respond to the varying sensitivities of communities to projects under different background noise conditions.

The noise criteria and descriptors for human annoyance depend on land use, as defined in Table 3-2. Further guidance on the definition of land use, the selection of the appropriate noise metric, and the application of these criteria are given in Section 3.2, with more detailed guidelines provided in Chapters 4 and 5.

Noise effects on livestock and wildlife also have been considered. There are no established criteria relating high-speed rail noise and animal behavior. However, some characteristics of high-speed rail noise are similar to low overflights of aircraft, and researchers generally agree that high noise levels from aircraft overflights can have a disturbing effect on both domestic livestock and wildlife. Some animals get used to noise exposure, while some do not. Documented effects range from simply taking notice and changing body position to taking flight in panic. Whether these responses represent a threat to survival of animals remains unclear, although panic flight may result in injuries to animals in rough terrain or in predation of unprotected eggs of birds. A limited amount of quantitative noise data relating actual levels to effects provides enough information to develop a screening procedure to identify areas where noise from high speed rail operations could affect domestic and wild animals. The basis for the screening is shown in Table 3-3. A summary of recent literature related to noise effects on livestock and wildlife is included in Appendix A.

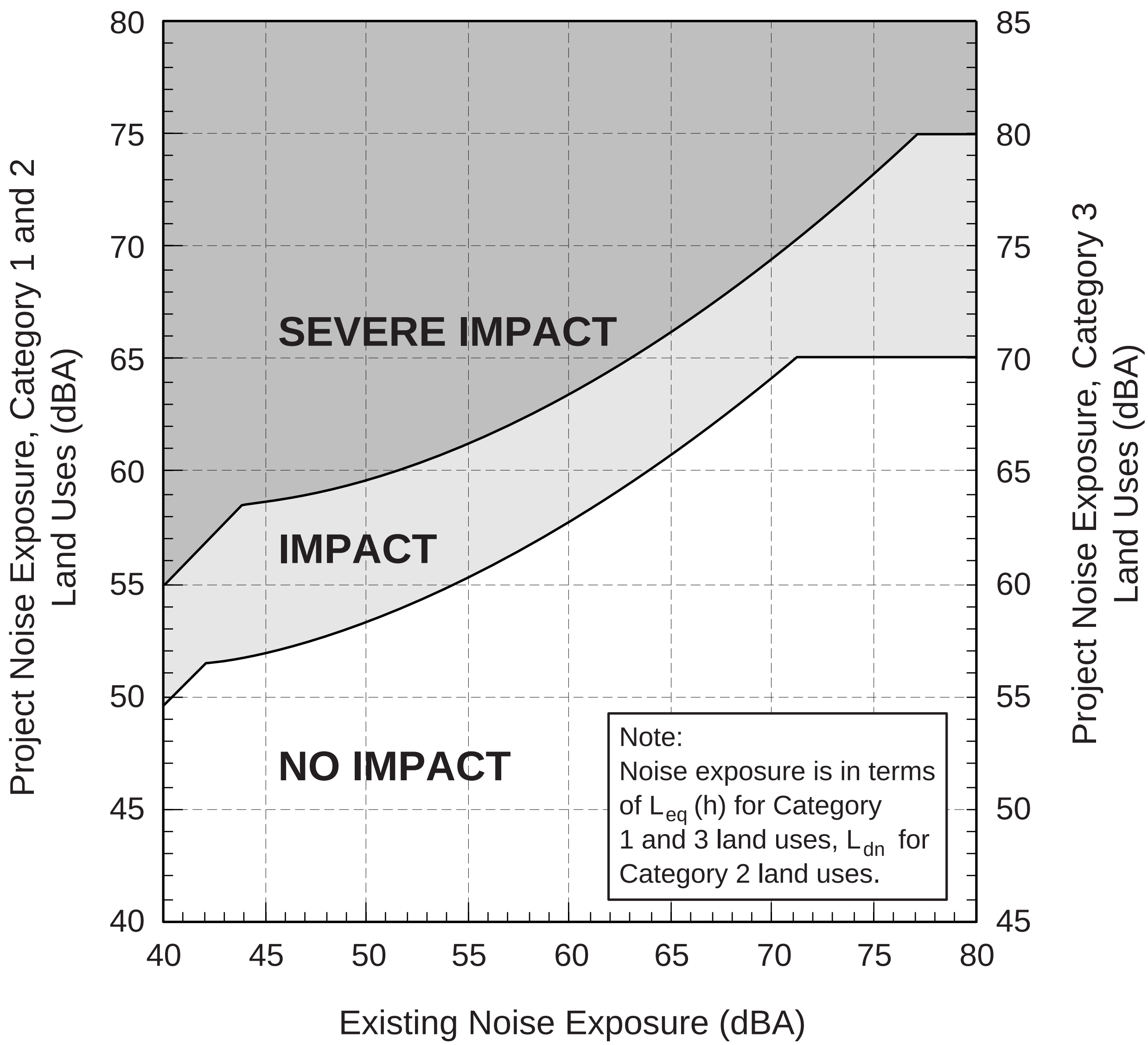


Figure 3-1 Noise Impact Criteria for High Speed Rail Projects

Table 3-1 Noise Levels Defining Impact for High Speed Rail Projects

Existing Noise Exposure* L_{eq}(h) or L_{dn} (dBA)	**Project Noise Impact Exposure,*** L_{eq}(h) or L_{dn} (dBA)					
	Category 1 or 2 Sites			**Category 3 Sites**		
	No Impact	Impact	Severe Impact	No Impact	Impact	Severe Impact
<43	< Ambient+10	Ambient + 10 to 15	>Ambient+15	<Ambient+15	Ambient + 15 to 20	>Ambient+20
43	<52	52-58	>58	<57	57-63	>63
44	<52	52-59	>59	<57	57-64	>64
45	<52	52-59	>59	<57	57-64	>64
46	<52	52-59	>59	<57	57-64	>64
47	<52	52-59	>59	<57	57-64	>64
48	<53	53-59	>59	<58	58-64	>64
49	<53	53-59	>59	<58	58-64	>64
50	<53	53-60	>60	<58	58-65	>65
51	<54	54-60	>60	<59	59-65	>65
52	<54	54-60	>60	<59	59-65	>65
53	<54	54-60	>60	<59	59-65	>65
54	<55	55-61	>61	<60	60-66	>66
55	<55	55-61	>61	<60	60-66	>66
56	<56	56-62	>62	<61	61-67	>67
57	<56	56-62	>62	<61	61-67	>67
58	<57	57-62	>62	<62	62-67	>67
59	<57	57-63	>63	<62	62-68	>68
60	<58	58-63	>63	<63	63-68	>68
61	<58	58-64	>64	<63	63-69	>69
62	<59	59-64	>64	<64	64-69	>69
63	<60	60-65	>65	<65	65-70	>70
64	<60	60-66	>66	<65	65-71	>71
65	<61	61-66	>66	<66	66-71	>71
66	<61	61-67	>67	<66	66-72	>72
67	<62	62-67	>67	<67	67-72	>72
68	<63	63-68	>68	<68	68-73	>73
69	<64	64-69	>69	<69	69-74	>74
70	<64	64-69	>69	<69	69-74	>74
71	<65	65-70	>70	<70	70-75	>75
72	<65	65-71	>71	<70	70-76	>76
73	<65	65-72	>72	<70	70-77	>77
74	<65	65-72	>72	<70	70-77	>77
75	<65	65-73	>73	<70	70-78	>78
76	<65	65-74	>74	<70	70-79	>79
77	<65	65-75	>75	<70	70-80	>80
>77	<65	65-75	>75	<70	70-80	>80

* L_{dn} is used for land use where nighttime sensitivity is a factor; L_{eq} during the hour of maximum transit noise exposure is used for land use involving only daytime activities.

Table 3-2 Land Use Categories and Metrics for High Speed Rail Noise Impact Criteria

Land Use Category	Noise Metric* (dBA)	Description of Land Use Category
1	Outdoor $L_{eq}(h)$**	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use.
2	Outdoor L_{dn}	Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor $L_{eq}(h)$**	Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, and churches, where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Buildings with interior spaces where quiet is important, such as medical offices, conference rooms, recording studios and concert halls fall into this category, as well as places for meditation or study associated with cemeteries, monuments, and museums. Certain historical sites, parks and recreational facilities are also included.

* Onset-rate adjusted sound levels (L_{eq}, L_{dn}) are to be used where applicable.
** L_{eq} for the noisiest hour of transit-related activity during hours of noise sensitivity.

Table 3-3 Interim Criteria for High Speed Rail Noise Effects on Animals

Animal Category	Class	Noise Metric	Noise Level (dBA)
Domestic	Mammals (Livestock)	SEL	100
	Birds (Poultry)	SEL	100
Wild	Mammals	SEL	100
	Birds	SEL	100

3.1.2 Definitions of Levels of Impact

The noise impact criteria are defined by two curves relating project noise levels to existing noise. Below the lower curve in Figure 3-1, a proposed project is considered to have no noise impact since, on the average, the introduction of the project will result in an insignificant increase in the number of people highly annoyed by the new noise. The curve defining the onset of noise impact stops increasing at 65 dB for Category 1 and 2 land use, a standard limit for an acceptable living environment as defined by a number of federal agencies. Project noise above the upper curve is considered to cause Severe Impact since a significant percentage of people would be highly annoyed by the new noise. This curve flattens out at 75 dB for Category 1 and 2 land use, a level associated with an unacceptable living environment. As indicated by the right-hand scale on Figure 3-1, the project noise criteria are 5 decibels higher for Category 3 land uses since these types of land use are considered to be slightly less sensitive to noise than the types of land use in categories 1 and 2.

The proposed project is judged to have an impact between these two curves, though not severe. The change in the cumulative noise level is noticeable to most people, but it may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation, such as the predicted level of increase over existing noise levels and the types and numbers of noise-sensitive land uses affected.

Although the curves in Figure 3-1 are defined in terms of the project noise exposure and the existing noise exposure, it is important to emphasize that the increase in the cumulative noise – when the project noise is added to existing noise – is the basis for the criteria. The complex shapes of the curves are based on the considerations of cumulative noise increase described in Appendix A. To illustrate this point, Figure 3-2 shows the noise impact criteria for Category 1 and 2 land use in terms of the allowable increase in the cumulative noise exposure. The horizontal axis is the existing noise exposure and the vertical axis is the increase in cumulative noise level due to the high-speed rail project. The measure of noise exposure is L_{dn} for residential areas and L_{eq} for land uses that do not have nighttime noise sensitivity. Since L_{dn} and L_{eq} are measures of total acoustic energy, any new noise source in a community will cause an increase, even if the new source level is less than the existing level. Figure 3-2 shows that the criterion for impact allows a noise exposure increase of 10 dBA if the existing noise exposure is 42 dBA or less but only a 1 dBA increase when the existing noise exposure is 70 dBA.

As the existing level of ambient noise increases, the allowable level of project noise increases, but the total allowable increase in community noise exposure is reduced. This reduction accounts for the unexpected result -- project noise exposure levels that are less than the existing noise exposure can still cause impact. The examples in Table 3-4 more clearly illustrate the levels of project noise and existing levels of exposure that result in crossing the threshold of impact.

Table 3-4 Noise Impact Criteria: Effect on Cumulative Noise Exposure

L_{dn} or L_{eq} in dBA (rounded to nearest whole decibel)			
Existing Noise Exposure	**Project Noise Exposure**	**Combined Total Noise Exposure**	**Noise Exposure Increase**
45	51	52	7
50	53	55	5
55	55	58	3
60	57	62	2
65	60	66	1
70	64	71	1
75	65	75	0

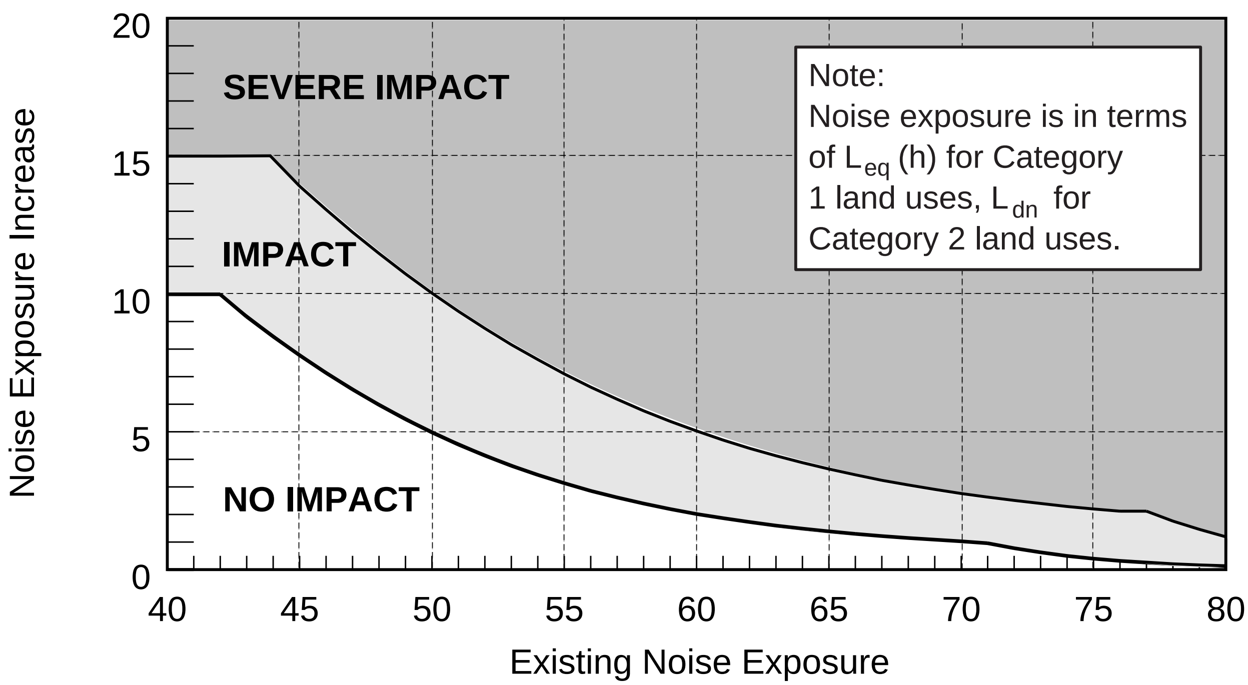


Figure 3-2 Increase in Cumulative Noise Levels Allowed by Criteria (Land Use Cat. 1 & 2)

Any increase in allowable noise exposure greater than shown in Table 3-4 will cause impact. This table shows that as the existing noise exposure increases from 45 dBA to 75 dBA, the allowed project noise exposure increases from 51 dBA to 65 dBA. However, the allowed increase in the cumulative noise level decreases from 7 dBA to 0 dBA (rounded to the nearest whole decibel). The justification for this decrease is that people already exposed to high levels of noise will notice and be annoyed even by only a small increase in the amount of noise in their community. In contrast, if the existing noise levels are quite low, a greater change in the community noise will be required for the equivalent level of annoyance. It should be noted that these annoyance levels are based on general community reactions to noise at varying levels that have been documented in scientific literature and do not account for specific community attitudinal factors that may exist.

3.2 APPLICATION OF NOISE IMPACT CRITERIA

This section provides practical guidance on interpretation of the land use categories and application of the impact criteria.

3.2.1 Noise-Sensitive Land Uses

As indicated in Section 3.1.1, the noise impact criteria and descriptors for human annoyance depend on land use, designated either Category 1, Category 2, or Category 3. Category 1 includes tracts of land where quiet is an essential element in their intended purpose, such as outdoor concert pavilions or National Historic Landmarks where outdoor interpretation routinely takes place. Category 2 includes residences and buildings where people sleep, while Category 3 includes institutional land uses with daytime and evening use, such as schools, places of worship, and libraries.

The criteria do not apply to most commercial or industrial uses because, in general, the activities within these buildings are compatible with higher noise levels. They do apply, however, to business uses that depend on quiet as an important part of operations, such as sound and motion picture recording studios.

Historically significant sites are treated as noise-sensitive depending on the land use activities. Sites of national significance with considerable outdoor use required for site interpretation would be in Category 1. Historical sites that are currently used as residences would be in Category 2. Historic buildings with indoor use of an interpretive nature involving meditation and study fall into Category 3. Category 3 sites include museums, significant birthplaces, and buildings in which significant historical events occurred.

Most busy downtown areas have buildings that are historically significant because they represent a particular architectural style or are prime examples of the work of an historically significant designer. If the buildings or structures are used for commercial or industrial purposes and are located in busy commercial areas, they are not considered noise-sensitive, and the noise impact criteria do not apply. Similarly, historical transportation structures, such as terminals and railroad stations, are not considered noise-sensitive sites. These buildings or structures are, of course, afforded special protection under Section 4(f) of the DOT Act and Section 106 of the National Historic Preservation Act. However, based strictly on how they are used and the settings in which they are located, these types of historical buildings are not considered noise-sensitive sites.

While parks are considered in general to be noise-sensitive sites, in some cases actual noise sensitivity depends on how the park is being used. Parks used for passive purposes such as reading, meditation, and conversation would be considered more noise-sensitive than ones used for sports or other active recreational pursuits.

3.2.2 Considerations in Applying the Noise Impact Criteria

The procedure for assessing Impact is to determine the existing noise exposure and the predicted project noise exposure at a given site, in terms of either L_{dn} or L_{eq}(h) as appropriate, and to plot these levels on Figure 3-1. In locations very near the right-of-way, the “onset-rate adjusted sound level” may be used (Figure 4-2). The location of the plotted point in the three impact ranges is an indication of the magnitude of the impact. For simplicity, noise impact also can be determined by using Table 3-1, rounding all noise level values to the nearest whole decibel before using the table. This level of precision is sufficient for determining the degree of noise impact at specific locations and should be adequate for most applications. However, a more precise determination of noise impact may be appropriate in some situations, such as estimating the distance from the project to which noise impact extends. In such cases, more precise noise limits can be determined using the criteria equations provided in Appendix A.

The noise criteria are to be applied outside the *building locations* for residential land use and at the *property line* for parks and other significant outdoor use. However, for locations where land use activity is solely indoors, noise impact may be less significant if the outdoor-to-indoor reduction is greater than for typical buildings (about 25 dB with windows closed). Thus, if the project sponsor can demonstrate that this is the case, mitigation may not be needed.

It is important to note that the criteria specify a comparison of future project noise with existing noise and *not* with projections of future "no-build" noise exposure (i.e., without the project). This is because comparison of a projection with an existing condition is more accurate than comparison of a projection with another projection. Furthermore, it should be emphasized that it is not necessary nor is it recommended that the existing noise exposure be determined by taking measurements at every noise-sensitive location in the project area. Rather, the recommended approach is to characterize the noise environment for "clusters" of sites based on measurements or estimates at representative locations in the community. In view of the sensitivity of the noise criteria to the existing noise exposure, careful characterization of the existing noise is important. Guidelines for selecting representative receiver locations and determining ambient noise are provided in Appendix B.

Application of criteria for livestock and wildlife provides information on the exposed area in which noise could have an effect, even if the consequences of those effects are not fully known. Researchers have observed both behavioral and physiological effects with the approximate single event sound levels listed in Table 3-3. The noise descriptors used by the researchers are not always well defined, but the best descriptor for a single event that incorporates both level and duration is the Sound Exposure Level (SEL). Procedures for calculating SEL for varying distances from high speed train passbys are described in Chapters 4 and 5. Criteria are not yet fully developed to the point where dose-response relationships can be fully described for different animal species. However, the assessment is based on the assumption that impact occurs when a noise event is sufficiently loud to generate an observable effect in domestic livestock or wildlife. The term “wildlife” is assumed to include all endangered species until species-specific information can be developed.

3.2.3 Mitigation Policy Considerations

FRA’s traditional approach to abatement of noise sources from high speed rail systems is embodied in its Railroad Noise Emission Compliance Regulation.[2] Rather than specific environmental regulations, the compliance regulation is intended to enforce the “Noise Emission Standards for Transportation Equipment: Interstate Rail Carriers” promulgated by the U.S. Environmental Protection Agency.[3] These Standards limit the amount of noise emitted from power cars and rail cars under stationary and moving conditions. In addition, the National Environmental Policy Act (NEPA) establishes a broad mandate for federal agencies to incorporate environmental protection and enhancement measures into the programs and

[2]U.S. Department of Transportation, Federal Railroad Administration,”Railroad Noise Emission Compliance Regulations,” Final Rule, 48 Federal Register 56756- 56761; December 23, 1983 (23 Code of Federal Regulations 210).

[3]U.S. Environmental Protection Agency, “Noise Emission Standards for Transportation Equipment: Interstate Rail Carriers,” 40 Code of Federal Regulations 201, July 1, 1984.

projects they help promote, approve and/or finance.[4] FRA strongly encourages noise abatement on high speed rail projects where noise impacts, and certainly where severe noise impacts are identified according to methods of this manual.

[4] United States Congress, National Environmental Policy Act of 1969; P.L. 91-190, January 1, 1970.

Chapter 4

INITIAL NOISE EVALUATION

This chapter contains procedures for an initial evaluation of potential noise impacts from a high-speed rail project. The goals of an initial noise evaluation are to identify the potential for impacts and to determine their order of magnitude, so that a more detailed analysis can be done where significant impacts are found in later phases of the design processes. The initial evaluation includes two parts: a preliminary screening of the project corridor to identify areas of potential impact, and a general noise assessment. The Screening Procedure is described in Section 4.1 and the General Assessment procedures are described in Section 4.2. An example of an initial noise evaluation appears at the end of this chapter. The initial evaluation results in an inventory of buildings where noise impact could occur and where noise mitigation measures, such as noise barriers, may be needed. In this regard, the method is designed to overstate the potential impact. This information is useful for comparing alternatives and selecting those with the least potential for noise impacts.

Noise from high-speed trains passing near noise-sensitive receptors is the focus of an initial evaluation. Except for special cases, other ancillary project noise sources, such as electrical sub-stations, roadway traffic near passenger stations, and maintenance facilities generally should not be considered at this stage of planning. Usually, a lack of detail on the design and placement of these types of noise sources precludes a meaningful noise assessment.

The screening procedure of the initial evaluation is based on the type of technology and the type of area the alignment is passing through. The screening procedure identifies whether impacts are likely to occur, but it does not attempt to predict noise exposure at specific receptors or to estimate the mitigation requirements. The screening procedure is appropriate for very early phases of a project when the design is still at a conceptual stage.

The General Assessment portion of the initial evaluation is based on noise source and land use information likely to be available at early stages in the project development process. The General Assessment includes estimating source level for the high-speed rail technology being considered, estimating existing noise exposure using a simplified procedure, determining noise impact based on the criteria given in Chapter 3, and preparing an inventory of the potential impacts and mitigation requirements. At the comparatively early planning stage, the General Assessment can help establish the most promising corridor locations.

4.1 NOISE SCREENING PROCEDURE

The Screening Procedure is based on very general assumptions and can be applied in the early phases of a project before specific project elements have been defined. The screening distances appropriate for the project are used to define the study area for any subsequent noise impact assessment. Distances for project types are listed in Table 4-1. When there are noise-sensitive receptors within the screening distance, impact is possible, and as the project definition evolves, the procedures for General (this chapter) and Detailed (Chapter 5) Noise Assessments are used to determine the extent and severity of impact.

The Screening Procedure indicates whether any noise-sensitive receivers are close enough to the proposed alignments for noise impact to be possible, and it identifies locations where the project has little possibility of noise impact. Screening can be useful when making a broad-brush comparison of potential impacts for different corridors. Screening also can be used to select the corridors that will be studied in more detail and to define the study area of any subsequent noise impact assessment. This selection can be a key element of a noise impact study since high-speed rail corridors may extend over hundreds of miles. Where no noise-sensitive land uses are within the screening distance, no further noise assessment is necessary. This approach allows the noise analysis to focus on locations where impacts are likely.

The Screening Procedure takes account of the noise impact criteria, the type of project, and noise-sensitive land uses. For screening purposes, all noise-sensitive land uses are considered to be in a single category. The distances given in Table 4-1 delineate a project’s noise study area. The areas defined by the screening distances are sufficiently large to encompass all potential impacts. The distances were developed using typical noise emissions of high-speed trains, but with the maximum number of operations and speeds of a given project type and the lowest applicable impact threshold from Chapter 3 to obtain worst case conditions. This approach gives a conservative estimate of impact. With the greater refinement in the general and detailed procedures, the noise impact distances should always be less than the screening distances listed in Table 4-1.

The Screening Procedure is applicable to high-speed rail projects using both steel-wheeled and maglev technologies. Screening distances by the type of corridor or alignment involved, either shared with an existing rail or highway corridor or newly built through undeveloped land, are listed in Table 4-1.

The steps for the Screening Procedure are:

Step 1. **Project Setting**. Determine the type of project corridor, and ambient noise environment, and locate them on Table 4-1. For many high-speed rail projects, the corridor can vary from one type to another, both in alignment characteristics and ambient environment, over the length of the project corridor. These variations should be identified and included when screening an entire project corridor.

Step 2. **Technology**. Determine the appropriate column (steel-wheel on steel rail or maglev) under Screening Distance in Table 4-1. Apply this distance from the guideway centerline.

Step 3. **Study Area Characteristics**. Within the distance noted above, locate any of the noise-sensitive land uses listed in Table 3-2.

Step 4. **Assessment**. If it is determined that none of the listed land uses are within the distances noted in Table 4-1, then no further noise analysis is needed. On the other hand, if one or more of the noise-sensitive land uses are within the screening distances noted in Table 4-1, then the project will require further analysis using the General Noise Assessment procedures described in the following sections.

Table 4-1 Screening Distances for Noise Assessments

Type of Project Corridor	Ambient Type	Screening Distance† for Project Type (feet)	
		Steel-Wheeled	**Maglev**
Shared with Existing Rail Line	Urban/Noisy Suburban	450	200
	Quiet Suburban/Rural	900	300
Shared with Existing Highway	Urban/Noisy Suburban	450	125
	Quiet Suburban/Rural	700	125
New Corridor (previously undeveloped land)	Urban/Noisy Suburban	450	200
	Quiet Suburban/Rural	900	350

† Measured from centerline of guideway or rail corridor

4.2 GENERAL NOISE ASSESSMENT

The General Noise Assessment determines the potential for noise impact by applying simplified models to estimate train noise and existing ambient noise, and then comparing the results with the impact criteria in Chapter 3. The procedure involves noise predictions commensurate with the level of detail of available data in the early stages of major investment planning. For projects in preliminary stages of planning, a general assessment may be all that is needed to evaluate noise impacts and to propose mitigation measures. The General Assessment also can be used to compare alternatives, such as locations of alignments or candidate high-speed transportation modes (steel-wheeled versus maglev technology), and can provide the appropriate level of detail about noise impacts for a corridor or sub-area study.

The general noise assessment procedure starts with determining the project noise level at a reference distance for the various project alternatives. This reference noise source level differs depending on the type of high-speed vehicle chosen for the project. The noise generated by each vehicle depends on the source characteristics described in Chapter 2. The reference noise source level is then used to compute noise exposure, accounting for anticipated operating conditions based on information about the project. At an early project stage, the information available may include:

- candidate technology or vehicle type,
- guideway variations,
- hours of operation,
- headways,
- design speed, and
- alternative alignments.

This information is not sufficient to predict noise levels at all locations along the right-of-way, but by using conservative estimates (for example, maximum design speeds and operations at design capacities) it is sufficient to estimate worst-case noise impacts.

The steps in the general noise assessment are described in detail in the following sections and are summarized below:

Step 1. Source Levels

- Place the alternative under study into one of three categories: steel-wheeled electric-powered, steel-wheeled fossil fuel-powered, or maglev.
- Determine the source reference level, which pertains to a typical passby of the project vehicle in a given speed range under reference operating conditions. *Use Table 4-2. The noise descriptor, SEL, used to define the reference level is discussed in Chapter 2. If L_{max} is available from source measurements or specifications, a conversion to SEL is necessary. Use the method described in Appendix C.*

Step 2. Project Operating Conditions

- Convert the source reference level to noise exposure in terms of L_{eq}(h) or L_{dn} at the reference distance of 50 feet under anticipated project operating conditions. *Use the appropriate equations contained in Table 4-4, depending upon the type of source.*

- Correct the noise exposure to account for vertical terrain effects, such as embankments and trenches. *Use the method described in Section 4.2.2.*

Step 3. Propagation Characteristics

- Draw a noise exposure-versus-distance curve for this source, which will show the project noise exposure as a function of distance, ignoring shielding. *Use the method described in Section 4.2.3.*
- Estimate the reduction in noise level to account for shielding attenuation from rows of buildings. *Use the general rule given at the bottom of Table 4-5. It is important to include adjustments for shielding attenuation from rows of buildings; omitting them can result in unrealistically high estimates of noise impact.*
- Draw an adjusted exposure-versus-distance curve.
- Identify noise-sensitive locations very close to the tracks where receivers may be startled by rapid onset rates of noise from high-speed trains. *The distance defining a potential startle zone is identified in Section 4.2.3.*

Step 4. Study Area Characteristics

- Estimate the existing noise exposure for areas adjacent to the project. *Use the methods described in Section 4.2.4.*

Step 5. Noise Impact Estimation

- Locate the distance at which project noise exposure results in impact corresponding to the estimated existing noise exposure, on a point-by-point basis. *Use the impact criteria from Chapter 3.*

- Connect the points to obtain a contour line around the project, which signifies the outer limits of impact.

Alternatively, when it is desired to compare different technologies:

- Determine contours corresponding to specific noise levels from the exposure-vs.-distance curves (for example, 60 dBA, 65 dBA, 70 dBA contours).

Step 6. Noise Impact Inventory

- Tabulate noise-sensitive land uses within the specific contours.

Step 7. Noise Mitigation

- Estimate the noise reduction that would be achieved with mitigation in the community areas where potential for impact has been identified.

- Repeat the tabulation of noise impacts after mitigation has been applied.

4.2.1 Noise Source Levels for General Assessment

The procedure starts with establishing the noise source levels, expressed in terms of SEL under reference conditions of speed, distance, and length. These quantities are given in Table 4-2 for the two general categories of high-speed trains: steel-wheeled (including both electric-and fossil fuel-powered locomotives) and maglev trains.

Reference SELs for each type of high-speed rail vehicle are given in Table 4-2 for the three speed regimes corresponding to propulsion, mechanical, and aerodynamic noise sources dominating the overall wayside noise. The speed regimes were discussed in Chapter 2. These speed regimes are defined by transition speeds, S_{t1} and S_{t2}, as well as speed-dependency coefficients K, which represent the slopes of the SEL versus speed curve in each regime. These parameters are included in Table 4-2. For each speed regime, the table also lists the reference SEL, reference speed, and reference length. These parameters are used in the equations of Table 4-4 to predict the noise exposure at 50 feet. A reference distance of 50 feet is used to minimize propagation effects.

Table 4-2 Reference Parameters at 50 feet from Track/Guideway

Reference Quantity	Abbreviation	Speed Regime	Vehicle Type		
			Steel-Wheeled		Maglev
			Electric	Fossil Fuel	
Reference SEL	SEL_{ref}	I	89 dBA	87 dBA	72 dBA
		II	93 dBA	94 dBA	73 dBA
		III	99 dBA	n/a	78 dBA
Speed Coefficient	K	I	3	5	2
		II	17	16	17
		III	47	n/a	50
Reference Speed	S_{ref}	I	20 mph	20 mph	20 mph
		II	90 mph	90 mph	60 mph
		III	180 mph	n/a	120 mph
Reference Length	len_{ref}	I	73 feet	73 feet	82 feet
		II	634 feet	634 feet	82 feet
		III	73 feet	n/a	82 feet
Transition Speed	S_{t1}	I → II	60 mph	60 mph	60 mph
	S_{t2}	II → III	170 mph	n/a	120 mph

A generalized plot of SEL as a function of speed, with each of the three speed regimes identified is shown in Figure 4-1. This plot illustrates use of several of the parameters listed in Table 4-2 in each of the three speed regimes. It differs from Figure 2-7 in that it plots SEL, not L_{max}, versus speed and represents the relationship as three discrete straight-line segments to approximate the smooth curve. The general equation relating SEL to speed for each speed regime at the reference distance (50 feet) is defined as:

$$SEL = SEL_{ref} + K \log\left(\frac{S}{S_{ref}}\right)$$

where S = train speed in miles per hour, and all other quantities are defined by the reference parameters given in Table 4-2. As indicated in Figure 4-1, the speed coefficient K represents the "slope" of the line in each speed regime.

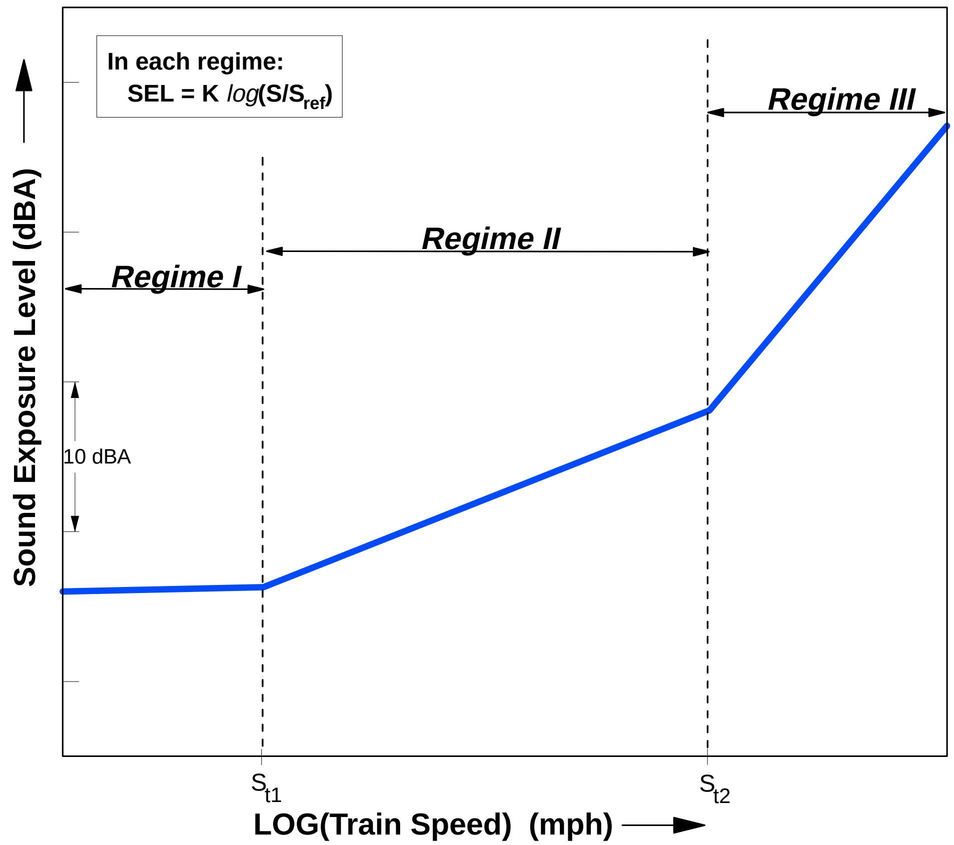


Figure 4-1 Generalized SEL vs Speed for a High-Speed Train Passby

4.2.2 Project Operating Conditions

After determining the reference level for the candidate high-speed rail technology, the next step is to determine noise exposure at 50 feet under project operating conditions and expressed in terms of L_{dn} and $L_{eq}(h)$. The additional data needed include:

- number of train passbys during daytime hours (defined as 7 a.m. to 10 p.m.) and nighttime hours (defined as 10 p.m. to 7 a.m.),

- maximum number of train passbys during hours that Category 1 or Category 3 land uses are normally in use (usually the peak-hour train volume),
- number and unit length of locomotives (power cars) and passenger coaches per train,
- speed (maximum expected), and
- guideway configuration.

Shielding. Attenuation from various types of shielding including noise barriers, also should be accounted for at this step of the process. Shielding attenuation depends primarily on geometrical factors relating the noise source, receiver, and intervening terrain or structures. The approximate noise reduction provided from the shielding effects of track layout such as trenches and embankments, as well as from "negative" shielding (i.e., noise increase) for elevated structures are provided in Table 4-3 . These noise reductions are given in terms of a correction factor, C_s, to be added to the reference SEL.

If noise mitigation is determined necessary at the end of the first pass of the General Assessment, Table 4-3 also gives the nominal noise reduction achieved by a 10-foot high wayside noise barrier, the most common mitigation measure for railway noise.

The equations necessary for calculating these quantities based on the reference SEL, adjusted to account for operating conditions, and the parameters listed here are listed in Table 4-4.

4.2.3 Propagation Characteristics

The process described in the Section 4.2.2 results in estimates of noise exposure at 50 feet for the proposed project. This section describes the procedure used to estimate the project noise exposure at other distances, resulting in a noise exposure versus distance relationship sufficient for use in a general assessment. The procedure is as follows:

1. Noise Exposure at 50 feet. Determine the L_{dn} or L_{eq} at 50 feet for the appropriate vehicle type using the equations in Table 4-4.

2. Attenuation with Distance. Adjust for the distance to the receiver using the equation:

$$L_{dn}\text{ (or }L_{eq})\Big|_{\text{at distance, }d} = L_{dn}\text{ (or }L_{eq})\Big|_{\text{at 50 feet}} - 15\log\left(\frac{d}{50}\right)$$

where d is the perpendicular distance from the receiver to the track centerline in feet. This equation gives an approximate relationship between noise exposure and distance that can be used to determine the noise impact contour for the first row of unobstructed buildings. This relationship can be plotted to display noise from both unmitigated and mitigated conditions to assess the benefits from mitigation measures.

Table 4-3 Shielding Corrections for Track Geometry

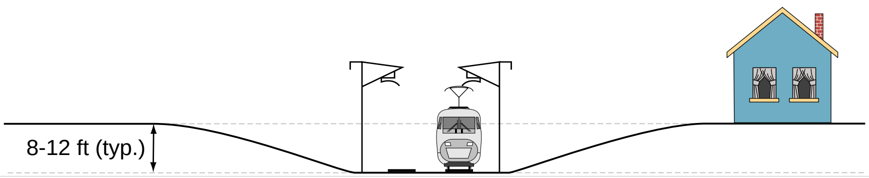
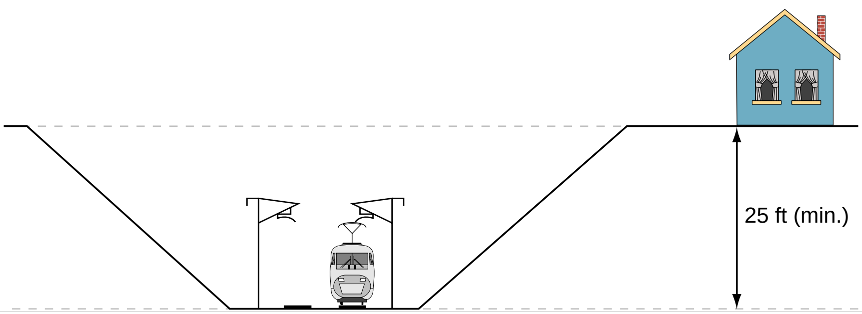
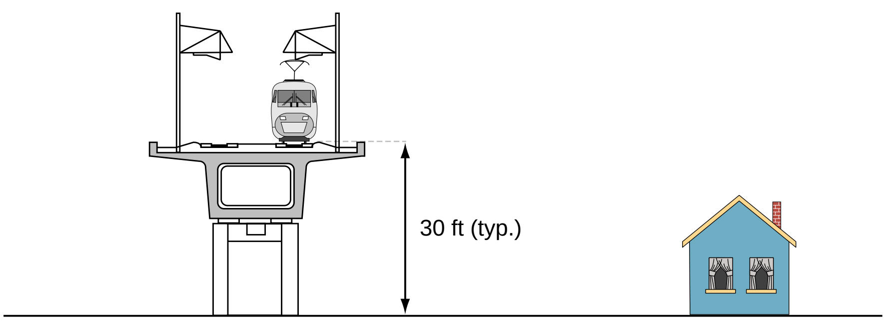
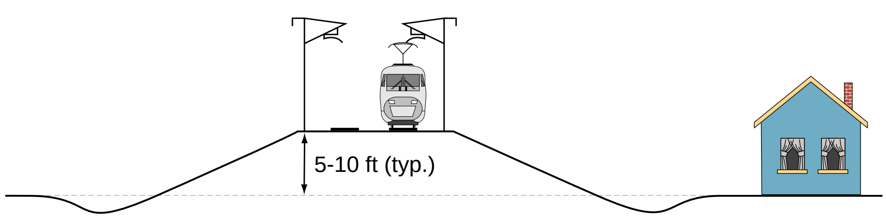
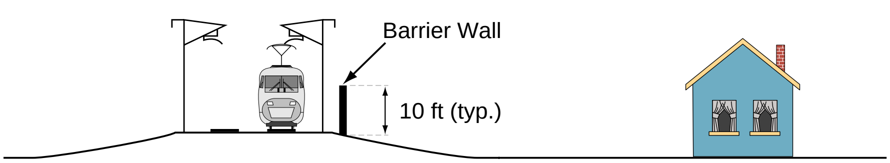
CASE	Speed Regime	Shielding Correction (C_s)
1) Tracks in Shallow Cut 	I	0 dBA
	II	–10 dBA
	III	–3 dBA
2) Tracks in Deep Trench or Cut 	I	–10 dBA
	II	–15 dBA
	III	–10 dBA
3) Tracks on Aerial Structure 	I	+4 dBA
	II	+4 dBA
	III	+2 dBA
4) Tracks on Embankment 	I	0 dBA
	II	–5 dBA
	III	0 dBA
5) Noise Barrier 	I	0 dBA
	II	–10 dBA
	III	–5 dBA

Table 4-4 Computation of Noise Exposure at 50 feet for General Assessment

Quantity	Equation
SEL at 50 ft:	$SEL = SEL_{ref} + K \log\left(\frac{S}{S_{ref}}\right) + 10 \log\left(\frac{len}{len_{ref}}\right)$
Hourly L_{eq} at 50 ft:	$L_{eq}(h) = SEL + 10 \log V + C_S - 35.6$
Daytime L_{eq} at 50 ft:	$L_{eq}(day) = L_{eq}(h)\Big\vert_{V = V_d}$
Nighttime L_{eq} at 50 ft:	$L_{eq}(night) = L_{eq}(h)\Big\vert_{V = V_n}$
L_{dn} at 50 ft:	$L_{dn} = 10 \log\left[15 * 10^{\left(L_{eq}(day) / 10\right)} + 9 * 10^{\left(L_{eq}(night) + 10 / 10\right)}\right] - 13.8$

$$len = \begin{cases} \text{total length of power unit(s), ft} \rightarrow & \text{in Speed Regime I} \\ \text{total train length, ft} \rightarrow & \text{in Speed Regime II} \\ \text{total train length, ft} \rightarrow & \text{in Speed Regime III} \end{cases}$$

S = train speed, in miles per hour

V = average hourly volume of train traffic, in trains per hour

V_d = average hourly daytime volume of train traffic, in trains per hour

$$= \frac{\text{number of trains from 7 am to 10 pm}}{15}$$

V_n = average hourly nighttime volume of train traffic, in trains per hour

$$= \frac{\text{number of trains from 10 pm to 7 am}}{9}$$

3. Shielding from Rows of Buildings. Account for shielding attenuation from rows of intervening buildings for second row receivers and beyond. Without accounting for shielding, impacts may be substantially over-estimated. Use the following general rules to determine the effect of shielding from intervening rows of buildings:

   - Assign 3 dB of shielding attenuation for the *first* row of intervening buildings only. (Attenuation means a subtraction from the sound level.)

   - Assign 1.5 dB of shielding attenuation for each subsequent row, up to a maximum total attenuation of 10 dB.

Startle Effects

As discussed in Chapter 2, there is considerable evidence that increased annoyance is likely to occur for train noise events with rapid onset rates. The relationship of speed and distance to define locations where the onset rate for high speed rail operations may cause startle, assuming open flat terrain with unobstructed view of the tracks in both directions is shown in Figure 4-2. The potential for startle for the most part is confined to an area very close to the tracks. For example, Figure 4-2 shows that 150 mph high-speed rail operations would have the potential for startle within 32 feet of the track centerline.

For the purposes of a General Noise Assessment, it is necessary only to identify noise-sensitive locations where startle may be an additional annoyance. The speed information contained in Figure 4-2 should be used to determine the distance within which startle could occur. Any noise-sensitive land use within that distance should be identified as a candidate for annoyance by startle.

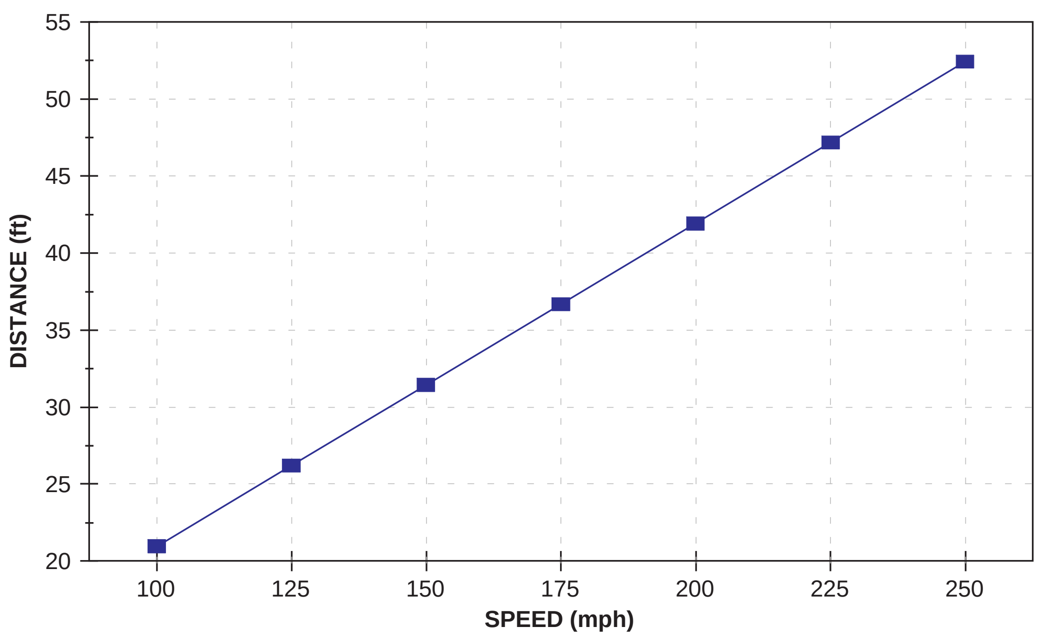


Figure 4-2 Distance from Tracks within which Startle Can Occur for HSR

4.2.4 Study Area Characteristics

The impact criteria described in Chapter 3 base the threshold of impact on estimates of existing noise exposure in the vicinity of the project. Impact is assessed using a combination of the existing noise exposure and the additional noise exposure that will be caused by the project. The Detailed Analysis procedures presented in Chapter 5 base the existing noise exposure on noise measurements at representative locations in the community. It is generally a good idea to base all estimates of existing noise on measurements, especially at locations known to be noise-sensitive. However, measurements are not always possible at the general assessment stage. This section gives procedures for estimating existing noise in the project study area from general data available early in project planning. The procedure uses Table 4-5, where a neighborhood's existing noise exposure is based on proximity to nearby major roadways or railroads or on population density. The process is as follows:

1. Mapping: Obtain scaled mapping and aerial photographs showing the project location and alternatives. A scale of 1 inch = 200 or 400 feet is appropriate for the accuracy needed in the noise assessment. The size of the base map should be sufficient to show distances of at least 1,000 feet from the center of the alignment.

2. Sensitive Receivers: Review the maps, together with land use information, to determine the proximity of the noise-sensitive land uses to the project and to the nearest major roadways and railroad lines. When necessary, windshield surveys or more detailed land use maps may confirm the location of sensitive receivers. For land uses more than 1,000 feet from major roadways or railroad mainlines (see definitions in Table 4-5), obtain an estimate of the population density in the immediate area, expressed in people per square mile.

3. Existing Noise Exposure: Use Table 4-5 to estimate existing noise exposure. Existing noise exposure is estimated by first looking at a site's proximity to major roads and railroad lines. If the site is located far enough from any major "linear" sources so that ambient noise is dominated by local streets and community activities, then the estimate should be based on population density alone. If the site is within about 1,000 feet of a major linear source, an estimate of the noise exposure from that source should be made based on generalized assumptions. Compare the noise levels from each of the three categories (roadways, railroads, and population density) and select the highest level to estimate the current exposure. In all cases, the noise levels are underestimated to provide a conservative impact assessment.

   Major roadways are separated into two categories: interstates, or roadways with four or more lanes that allow trucks; and "others," parkways without trucks and city streets with the equivalent of 75 or more heavy trucks per hour or 300 or more medium trucks per hour. The estimated roadway noise levels are based on data for light to moderate traffic on typical highways and parkways using the FHWA[1] highway noise prediction model. Where a range of distances is given, the predictions are made at the outer limit, thereby underestimating the traffic noise at the inner distance. For highway noise, distances are measured from the centerline of the near lane for roadways with two

[1] U.S. Department of Transportation, Federal Highway Administration, "FHWA Highway Traffic Noise Prediction Model," FHWA-RD-77-108, December 1978.

lanes, while for roadways with more than two lanes the distance is measured from the geometric mean of the roadway, computed as follows:

$$D_{GM} = \sqrt{(D_{NL})(D_{FL})}$$

where:

D_{GM} is the distance to the geometric mean, D_{NL} and D_{FL} are distances to the nearest lane and farthest lane centerlines, respectively.

For railroads, the estimated noise levels are based on an average train traffic volume of 5 to 10 trains per day at 30 to 40 mph for mainline railroad corridors, and the noise levels are provided in terms of L_{dn} only. Distances are referenced to the track centerline or, in the case of multiple tracks, to the centerline of the rail corridor. Because of the intermittent nature of train operations, train noise will affect the L_{eq} only during certain hours of the day, and these hours may vary from day to day. To reduce the chance of inaccurate estimates of noise impact when using the one-hour L_{eq} descriptor, the L_{eq} at sites near rail lines should be estimated based on nearby roadways or population density unless very specific train information is available.

In areas away from major roadways, noise from local noise sources is estimated using a relationship determined by the U.S. EPA.[2] EPA determined that ambient noise can be approximately related to population density in locations away from transportation corridors, such as airports, major roads, and railroad tracks, according to the following relation:

$$L_{dn} = 22 + 10 \log (p) \qquad \text{(in dBA)}$$

where p = population density in people per square mile.

4. Measurements to estimate existing noise from a shared rail transit corridor: If the proposed high-speed rail project corridor is to be shared with an existing rail transit corridor (rapid transit, commuter rail, etc.), the methods described in Steps 1 through 3 are not adequate to characterize existing noise exposure accurately. Since existing noise exposure is a strong function of distance from the existing rail corridor, general estimates such as those presented in Table 4-5 are difficult to make, given the high variability in the operational characteristics of transit systems. In such cases, noise measurements at representative locations along the corridor are essential to estimate existing noise accurately.

The procedure for the Detailed Noise Analysis (Chapter 5) recommends that these measurements be supplemented and/or substantiated through noise prediction methods developed specifically for

[2]U.S. Environmental Protection Agency, "Population Distribution of the United States as a Function of Outdoor Noise Level," Report 550/9-74-009, June 1974.

different transit modes. These methods are provided in the guidance manual published by US Department of Transportation, Federal Transit Administration.[3]

4.2.5 Noise Impact Estimation

It is often desirable to draw noise impact contours on land use maps to aid the impact inventory. Once the contours are on the map, the potential noise impacts can be estimated by counting the buildings inside the contours. The process is as follows:

1. Project versus Existing Noise Exposure. Identify the noise-sensitive neighborhoods and buildings and estimate existing noise exposure following the procedures described in Section 4.2.4. Use the estimate of existing noise exposure and the noise impact criteria in Figure 3-1 to determine how much additional noise exposure would need to be created by the project before there would be Impact or Severe Impact.
2. Noise Impact Contours. Determine the distances from the project boundary to the two impact levels using the noise exposure-versus-distance relationships from Section 4.2.2. Plot points on the land use map corresponding to those distances in the neighborhood under study. Continue this process for all areas surrounding the project. Connect the plotted points by lines to represent the noise impact contours.
3. Noise Exposure Contours. Alternatively, if it is desired to plot specific noise contours at, for example, 65 dBA, the distances also can be determined directly from the approach described in Section 4.2.2. Again, plot the points associated with a given noise level on the land use map and connect by lines to represent that contour.

The impact contour will change with respect to the project boundary as the existing ambient exposure changes, as project source levels change, and as the amount of acoustical shielding changes. In general, the points should be placed close enough to allow a smooth curve to be drawn. For a General Assessment, the contours may be drawn through buildings and salient terrain features as if they were not present. This practice is acceptable considering the level of detail associated with a project in its early stages of development.

4.2.6 Noise Impact Inventory

The next step in the General Assessment is to develop an inventory of noise-sensitive land uses that are within the impact contours. Use land use information and the noise impact contours developed in Section 4.2.5 to count buildings within the impact contours. In some cases it may be necessary to supplement the land use information or to determine the number of dwelling units within a multi-family building with a visual survey.

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[3] US Department of Transportation, Federal Transit Administration, Transit Noise and Vibration Impact Assessment, Report No. DOT-T-95-16, April 1995.

Table 4-5 Estimating Existing Noise Exposure for General Assessment

Distance from Major Noise Source[1] (feet)			Population Density (people per sq mile)	Noise Exposure Estimates (dBA)			
Interstate Highways[2]	Other Roadways[3]	Railroad Lines[4]		L_{eq} Day	L_{eq} Evening	L_{eq} Night	L_{dn}
10 - 49				75	70	65	75
50 - 99				70	65	60	70
100 - 199				65	60	55	65
200 - 399				60	55	50	60
400 - 799				55	50	45	55
800 and up				50	45	40	50
	10 - 49			70	65	60	70
	50 - 99			65	60	55	65
	100 - 199			60	55	50	60
	200 - 399			55	50	45	55
	400 and up			50	45	40	50
		10 - 29		--	--	--	75
		30 - 59		--	--	--	70
		60 - 119		--	--	--	65
		120 - 239		--	--	--	60
		240 - 499		--	--	--	55
		500 - 799		--	--	--	50
		800 and up		--	--	--	45
			1 - 99	35	30	25	35
			100 - 299	40	35	30	40
			300 - 999	45	40	35	45
			1,000 - 2,999	50	45	40	50
			3,000 - 9,999	55	50	45	55
			10,000 - 29,999	60	55	50	60
			30,000 and up	65	60	55	65

Notes:

1. Distances do not include shielding from intervening rows of buildings. General rule for estimating shielding attenuation in populated areas: Assume 1 row of buildings every 100 ft; -4.5 dB for the first row, -1.5 dB for every subsequent row up to a maximum of -10 dB attenuation.
2. Roadways with 4 or more lanes that permit trucks, with traffic at 60 mph.
3. Parkways with traffic at 55 mph, but without trucks, and city streets with the equivalent of 75 or more heavy trucks per hour and 300 or more medium trucks per hour at 30 mph.
4. Main line railroad corridors typically carrying 5 to 10 trains per day at speeds of 30 to 40 mph.

The steps for developing the inventory are:

1. Construct tables for all the noise-sensitive land uses identified in the three land-use categories from Chapter 3.

2. For each alternative, tabulate buildings and sites that lie within the impact contours. For residential buildings, estimate either the number of buildings or number of dwelling units. Other pertinent information, such as existing noise levels, corridor segment delineations and expected train speed also may be useful in tabulating the impacts. An example table is shown in Table 4-6.

3. Prepare summary tables showing the number of buildings and dwelling units within each impact zone for each alternative. Utilize the summary table to compare the alternatives, including those with and without noise mitigation measures.

4. Determine the possible need for mitigation based on the degree of impact and appropriate policy considerations.

Table 4-6 Sample Noise Impact Inventory Table

Alignment: 1
Scenario: HS-Electric

Corridor Segment			Existing Ldn (dBA)	Avg Train Speed (mph)	Distance to Contour (ft)		Impact Inventory without mitigation (Number of Buildings)					
Description	Milepost				Impact	Severe Impact	Impact			Severe Impact		
	From	To					SF	MF	Inst	SF	MF	Inst
Downtown Area	0.0	4.6	70	50	45	25	0	2	0	0	0	0
Inside I-95	4.6	5.7	65	80	70	40	6	1	0	0	0	0
To Route 100	5.7	9.5	65	100	80	45	12	0	0	2	0	0
To Pleasant St	9.5	12.0	65	60	60	30	1	0	0	0	0	0
Smithtown Station	12.0	12.2	60	25	40	20	0	0	0	0	0	0
Lakeville mountains	12.2	20.8	55	80	80	40	1	0	0	0	0	0
Central Valley	20.8	26.9	60	110	100	55	7	0	0	4	0	0
To Rt 66 crossing	26.9	33.4	60	125	110	65	6	0	1	2	0	0
I-84 corridor	33.4	41.6	65	140	125	75	14	0	1	5	0	1
To South St	41.6	44.2	65	80	70	40	2	0	0	1	0	0
Business District	44.2	46.2	65	55	60	30	0	1	0	0	0	0
Springfield Station	46.2	46.4	65	25	40	20	0	0	0	0	0	0

SF: Single-Family Residential
MF: Multi-Family Residential
Inst: Institutional (schools, churches, hospitals)

4.2.7 Noise Mitigation Requirements

The final step of the General Assessment is to estimate the noise mitigation measures required to minimize the number of impacts. The primary noise control treatment for steel-wheeled high-speed rail systems is the installation of wayside noise barriers.[4] The approximate noise barrier lengths and locations developed in a general assessment will provide a preliminary basis for evaluating the costs and benefits of impact mitigation. This section provides guidelines for making order-of-magnitude cost estimates for noise barriers based on the length of barrier required. A more complete description of

[4] Due to the unique characteristics of maglev systems, noise control considerations are likely to be made at the outset as an integral part of the system design. Retrofitting a maglev system for noise mitigation measures such as sound barriers is likely to incur great costs. Such design options as building sidewalls into the guideway structure, using a concrete rather than a steel guideway, and minimizing structural vibrations of the guideway and vehicle through design are noise control measures that can be taken as a baseline condition. As a result, it may not be applicable to estimate preliminary mitigation without more detailed information on system design.

noise mitigation, with consideration given to other available mitigation treatments applied at the source, path, or receiver, and the benefits resulting from each is provided in Chapter 5.

Train noise barriers need to be high enough to effectively block the line of sight between the noise source and the receiver. The dominant source of train noise over most operating speeds for steel-wheeled high-speed rail, as with conventional rail systems, is wheel-rail interaction. To shield this noise effectively, relatively low barriers located close to the track are usually sufficient. A barrier with its top edge 6 to 8 feet above the top of rail at the right-of-way line usually achieves effective shielding. A barrier at this height above the top of rail can reduce wheel-rail noise by 8 to 10 dBA.

The attenuation of sound by a barrier is frequency dependent; all other things being equal, the higher the frequency of the noise, the greater the barrier attenuation. Because the sound energy for aerodynamic sound sources is in the low frequencies (below 500 Hz) these sources are inherently difficult to shield with a barrier. Further, because the sound level due to aerodynamic sources increases rapidly with increasing speed, a standard 8-foot barrier is less effective at high speeds, where aerodynamic sources dominate the overall sound level.

A relatively low barrier will not shield sound sources located high above the guideway, since such sources would protrude above the top of the barrier. This noise includes noise from propulsion sources, such as cooling fans, as well as aerodynamic noise generated at the upper part of the train. A description of these sources is presented in Chapter 2.

The following steps can be applied in making a preliminary estimate of the noise mitigation measures that might be required following an initial evaluation of noise impact:

1. Barrier Height. Assume an average noise barrier height of 8 feet as a cost-effective mitigation measure for high-speed rail noise impact. If shielding noise from higher noise sources (such as propulsion units) or protecting higher floors of residences is required, assume a 16-foot-high barrier.

2. Barrier Length. In addition to height, determine the length of noise barriers needed to extend far enough to each side of the affected receiver so that train noise from beyond the ends of the barrier does not significantly degrade its acoustical performance. As a rule, the barrier should be long enough to shield the entire train length for an angle of at least 60 degrees in either direction.

3. Barrier Cost. Make a mitigation cost estimate based on the average height and length, assuming a unit cost of $20 per square foot. Use this cost to perform a cost-benefit analysis, if required.

4. Barrier Effectiveness. Assume a net barrier attenuation of 5 dBA for an 8 foot-high barrier, and 8 dBA for a 16-foot-high barrier. These attenuations are applicable to both L_{eq} and L_{dn}. Reassess impact with mitigation based on these reductions using the methods in this chapter.

It is important to note that the barrier estimates made in the initial evaluation are preliminary. Detailed barrier designs should be developed during the final engineering phase of the project. Some of the factors to be addressed during the final engineering phase are the structural, aesthetic, and acoustical feasibility of the barriers, as well as their cost effectiveness with respect to their acoustical benefits. The barriers should be constructed if they are found to be practical and prudent.

Examples 4-1 and 4-2 provide two examples of noise analyses utilizing the procedures presented in this chapter. Example 4-1 illustrates the Initial Noise Evaluation procedure for a representative high-speed rail project alternatives analysis, including both the Noise Screening and General Assessment. The source reference levels used in the analysis are taken directly from Table 4-2, since it is assumed that at this stage measurements or specifications of the equipment are unknown. Example 4-2 demonstrates the conversion of a measured or specified L_{max} to the appropriate source reference level in SEL for use in the General Assessment procedure, using the methods presented in Appendix C.

Example 4-1. Initial Noise Evaluation Comparing Two High-Speed Rail Alignments

This example illustrates the initial noise evaluation procedure for a hypothetical high-speed rail project. The project involves an alternatives analysis of a proposed steel-wheeled high-speed rail system to serve a 200-mile intercity corridor. Two alignment options are available, characterized by the following typical corridor segments:

Alignment Alternative 1: A direct route through primarily undeveloped, rural areas with farmland and scattered residences within 1,000 feet of the corridor. The track would be welded rail on ballast and concrete ties at-grade, designed for a maximum speed of 160 mph.

Alignment Alternative 2: Along the median of a busy multi-lane interstate highway (typical vehicle speeds of 60 to 70 mph during freely flowing conditions), passing through a densely developed area with mixed residential and commercial land use. The alignment would be fully grade-separated, with welded rail on aerial structure (direct-fixation track on concrete slab), and with a maximum design speed of 160 mph. An example of a typical corridor segment is illustrated by the plan map in Figure 4-3. The closest unobstructed residences are 80 to 200 feet from the median centerline.

Assumptions

The assumptions for the project are the same for both alignment alternatives and are as follows:

- **Proposed System:** Steel-wheeled electrically powered high-speed train consisting of two power cars (one on each end) and 10 passenger coaches. Unit length of each power car is 73 feet, unit length of each passenger coach is 63 feet.
- **Proposed Service:** Total of 57 trains per day operating between 6:00 a.m. to 11:00 p.m.. Headways are 20 minutes during daytime hours (7 a.m. to 10 p.m.) the day, 20 minutes during nighttime hours (10 p.m. to 12 a.m., 5 a.m. to 7 a.m.) This service results in the following average hourly volumes:

$$V_D = 3 \text{ trains/hour}$$
$$V_N = 1.33 \text{ trains/hour}$$

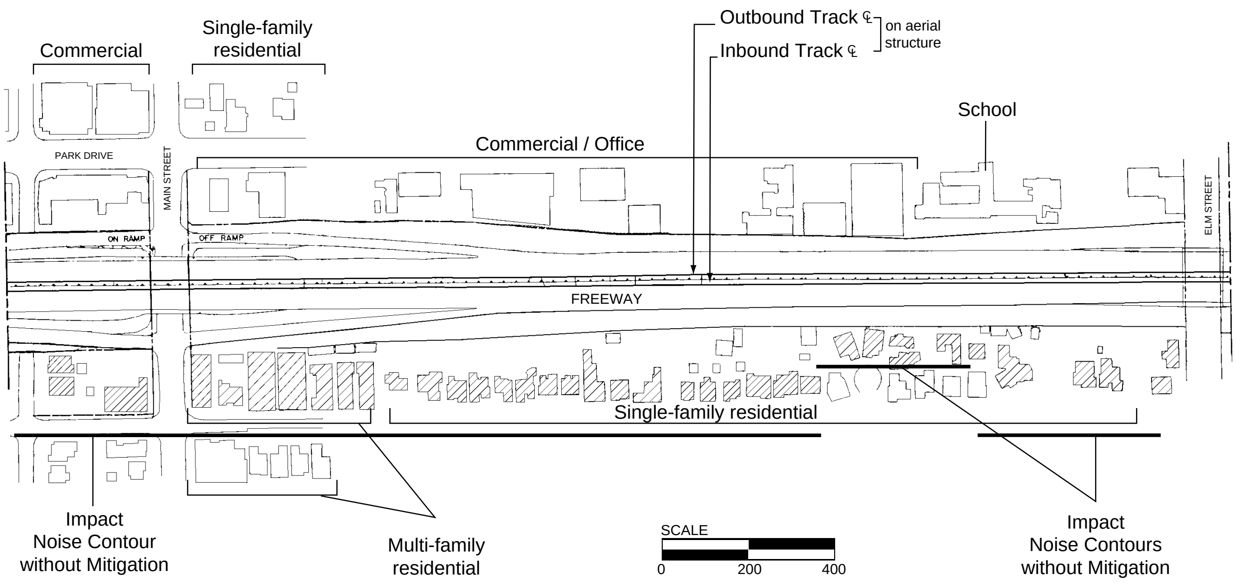

Figure 4-3. Typical Corridor Segment for Example 4-1, Alignment Alternative 2

Procedure

For steel-wheeled systems, the screening procedure (Table 4-1) calls for additional analysis for noise-sensitive land use within 450 feet of a shared corridor-type right-of-way, and 900 feet of a new corridor through undeveloped land, thereby requiring further noise analysis for both alternatives. The procedure is summarized as follows:

Determination of Noise Exposure at 50 feet

1. Determine reference SEL at 50 feet and parameters for proposed system
   Table 4-2 indicates that the maximum design speed of 180 mph puts the system in speed regime III (aerodynamic). Thus, the following parameters are applied:

   SEL_{ref} = 93 dBA
   K = 17
   S_{ref} = 90 mph
   len_{ref} = 634 feet

   The actual source length is defined in Table 4-4 as the total train length, which is calculated as:

len = power cars + coaches = 776 feet

Using the first equation in Table 4-4, adjust to SEL at 50 feet for actual operating conditions,

$$\begin{aligned} SEL &= SEL_{ref} + K\log(S/S_{ref}) + 10\log(len/len_{ref}) \\ &= 93 + 17\log(160/90) + 10\log(776/634) \\ &= 98.1 \text{ dBA, or } 98 \text{ dBA (rounded).} \end{aligned}$$

2. Calculate $L_{eq}(h)$ and L_{dn} at 50 feet, adjusting for track geometry
For Alignment 1, the track is at-grade so there is no shielding adjustment for track geometry, i.e., $C_s = 0$. Thus, using the equations in Table 4-4,

$$\begin{aligned} L_{eq}(day) &= SEL + 10\log(V_d) + C_s - 35.6 \\ &= 93 + 10\log(3) + 0 - 35.6 = 67.3 \text{ dBA} \\ L_{eq}(night) &= SEL + 10\log(V_n) + C_s - 35.6 \\ &= 98 + 10\log(1.33) + 0 - 35.6 = 63.8 \text{ dBA} \end{aligned}$$

and, L_{dn} = 70.9 dBA, or 71 dBA (rounded)

For Alignment 2, speed regime III, Table 4-3 indicates that C_s = +2 dBA for aerial structure. Thus,

$$\begin{aligned} L_{eq}(day) &= 98 + 10\log(3) + 2 - 35.6 = 69.3 \text{ dBA} \\ L_{eq}(night) &= 98 + 10\log(1.33) + 2 - 35.6 = 65.8 \text{ dBA} \end{aligned}$$

and, L_{dn} = 72.9 dBA, or 73 dBA (rounded)

Estimate Propagation of Project Noise Exposure with Distance

3. Apply Noise Exposure-Versus-Distance Relationship
Using the method described in Section 4.2.3, the distance correction equation is applied to the project L_{dn} at 50 feet. A resulting curve of L_{dn} versus distance is obtained for each alignment option, as shown in Figure 4-4.

Estimate Existing Noise Exposure

4. Estimate existing noise at noise-sensitive sites
For Alignment 1, there are no major roadways or rail lines contributing to the existing ambient noise. Thus, the existing noise exposure should be estimated based on population density. For a predominantly rural area, a population density of 300-1000 people/square mile can be assumed, yielding an ambient L_{dn} of **45 dBA** (from Table 4-5). From Figure 3-1, the corresponding project noise exposure L_{dn}s causing impact for Category 2 land uses (residential) are 52 dBA and 59 dBA, for Impact and Severe Impact, respectively.

For Alignment 2, the highway (the dominant noise source) is a major linear source from which noise attenuates rapidly with distance. Thus, it would be inaccurate in this case to assign a single "generalized" noise level to characterize a large area, as for Alignment 1. The existing noise exposure should be estimated as a function of distance from the highway on a site-specific basis.

From Figure 4-3, unobstructed residences range from 80 to 200 feet from the highway. Based on the information in Table 4-5 the L_{dn} is 70 dBA for residences closer than 100 feet from a major interstate highway, and 65 dBA for residences between 100 and 200 feet.

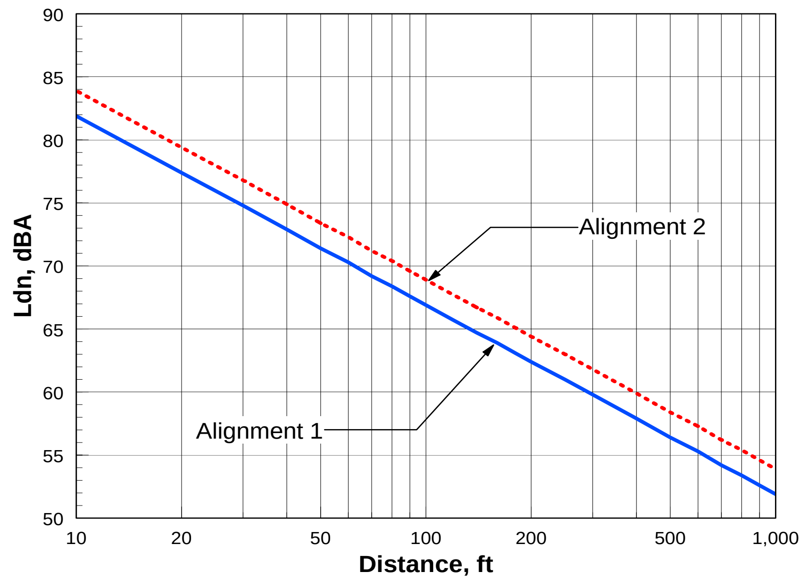

Figure 4-4. Project Noise Exposure vs Distance for Example 4-1

Applying the impact criteria curves in Figure 3-1, the project noise levels that cause impact for Alignment 2 are listed in the following table:

Distance to Highway	Existing Noise, L_{dn}	Project L_{dn} Criterion	
		Onset of Impact	Onset of Severe Impact
50 - 99 ft	70 dBA	64 dBA	69 dB
100 - 200 ft	65 dBA	61 dBA	66 dB

Even though the criteria allow for a higher project L_{dn} for Alignment 2 than for Alignment 1 due to the higher existing noise environment, the net allowable increase is less for Alignment 2 (1 to 4 dB) than for Alignment 1 (8 to 14 dB).

Noise Impact Contours

5. <u>Determine Distances to Impact and Severe Impact</u>
Distance-to-impact contours for each alignment are determined by extrapolating along the curves in Figure 4-4 and the project impact thresholds defined in Step 4. The results are summarized as follows for the residences and school:

Alternative	Distance	Existing Noise, L_{dn}	Distance to Noise Impact Threshold, feet	
			Impact	Severe Impact
Alignment 1	1000 ft	45 dBA	980	330
Alignment 2	50 - 99 ft	70 dBA	200	90
	100 - 200 ft	65 dBA	330	150

6. Draw Noise Impact Contours
Draw contours for each affected residence based on the distances given in the table in Step 5. The impact distances are defined in terms of distance from the project corridor centerline.

For Alignment 2, the Impact contours are shown in Figure 4-3. The Severe Impact contours do not go beyond the edge of the highway and are thus omitted for simplicity. The impact noise contours are drawn at the two different distances, 200 feet and 350 feet, resulting from the change in existing noise based on distance to the highway. 38 residential buildings are located within the contours defining Impact (shaded in Figure 4-3).

7. Estimate Startle Effects/Wildlife
For either alignment, the distance within which startle could occur is the same. Using a speed of 160 mph in Figure 4-2 results in a distance of approximately 33 feet within which a person could be startled by a high-speed train. None of the buildings in Alignment 2 is within that distance.

The distance within which wildlife could be disturbed also should be evaluated. According to Table 3-3, whenever the SEL exceeds 100 dBA there is a potential for effects on animals. Using Alignment 1 as a likely example, the SEL at 50 feet is 98 dBA. Using the propagation equation given in Section 4.2.3 with SEL in place of L_{eq} (which is valid since both are sound energy descriptors), the distance "d" becomes 37 feet for SEL = 100 dBA. Consequently, wildlife could be disturbed within 37 feet of the tracks in Alignment 1.

End of Example 4-1

Example 4-2. Conversion of Specified L_{max} to Source Reference Level in SEL

In the previous example, Alignment 2 is chosen as the preferred project alternative. The proposed system is modeled on a European high-speed electric trainset with the following noise performance:

L_{max} = 86 dBA, measured at a distance of 82 ft from track centerline and a speed of 100 mph,

which puts us in **Regime II** for the General Assessment.

The steps to convert L_{max} to the equivalent source reference levels for use in the General Assessment, instead of the tabulated value in Table 4-2, are as follows:

1. Convert to SEL under specified conditions
The parameters needed to evaluate the third equation in Table C-2 of Appendix C are:

len = 776 feet,

S = 100 mph,

d = 82 feet, and

$$\alpha = \arctan\left(\frac{len}{2d}\right) = 1.36$$

Substituting into this equation we get SEL at the specified distance and speed:

$$SEL = 86 + 10\log\left(\frac{776}{100}\right) - 10\log(2\times1.36) + 3.3 = 93.9 \text{ dBA, or 94 dBA (rounded)}$$

2. <u>Normalize to reference conditions of Table 4-2</u>
Use the fourth equation in Table C-2 to normalize the SEL to the appropriate reference parameters in Table 4-2, for comparison with the tabulated level. The following values are required from Table 4-2:

K = 17,
S_{ref} = 90 mph, and
len_{ref} = 634 feet.

Evaluating the fourth equation in Table C-2 yields:

$$SEL_{ref} = SEL + K\log\left(\frac{S_{ref}}{S}\right) + 10\log\left(\frac{len_{ref}}{len}\right) - 15\log\left(\frac{50}{d}\right)$$

SEL_{ref} = 95.4 dBA, or 95 dBA (rounded).

Thus, this value of SEL_{ref}, based on the specified L_{max}, is 2 dBA higher than the tabulated value, 93 dBA, in Table 4-2 for a steel-wheeled electric train in this speed regime.

End of Example 4-2

Chapter 5

DETAILED NOISE ANALYSIS

Procedures for performing a comprehensive assessment of noise impact for proposed high-speed rail projects are presented in this chapter. The Detailed Noise Analysis allows site-specific noise predictions and mitigation evaluations. Considerably more precision can be achieved with the Detailed Noise Analysis than is possible with the General Assessment described in Chapter 4. While the General Assessment involves the use of generalized, overall noise source levels and simplified noise projection models, a Detailed Noise Analysis considers the noise from each subsource component, with each component defined in terms of a noise-generating mechanism (e.g., propulsion, wheel-rail, aerodynamic), reference noise level, location along the train, and speed dependency. The Detailed Noise Analysis also uses more precise methods to estimate adjustments for horizontal and vertical geometry, ground absorption, and shielding. Although the Detailed Noise Analysis procedures present all the information needed to predict noise and assess impact under "normal" circumstances, sometimes it will be appropriate to adapt the procedures using practical engineering judgement to reflect a project's specific design parameters.

The Detailed Noise Analysis is appropriate for assessing noise impacts for high-speed rail projects after the preferred alignment and candidate high-speed rail technologies have been selected. At this point the preliminary engineering has been initiated and the preparation of an environmental document (usually an Environmental Impact Statement) has begun. Information required to perform a Detailed Noise Analysis includes type of vehicle equipment to be used, train schedules, speed profiles, plan and profiles of guideways, locations of access roads, and landform topography, including adjacent terrain and building features.

Equations, rather than graphs or tables of numbers, are used in these procedures as the primary mode of computation to allow the use of spreadsheets and/or programmable calculators. These equations and their supporting text have been streamlined in this chapter to provide a concise view of the Detailed Noise Analysis. Background information on noise concepts and the basics of high-speed rail noise are presented in Chapter 2 and Appendix A.

The steps in performing the Detailed Analysis parallel the steps for the General Noise Assessment, although more refined procedures are used to predict project noise and evaluate mitigation measures. The steps are outlined below.

Existing Conditions

Step 1. **Noise Sensitive Receivers**. Guided by the information in Section 5.1.1, identify noise-sensitive receivers. The number of receivers will depend upon the land use in the vicinity of the proposed project and the extent of the study area defined by the screening procedure described in Chapter 4. An initial evaluation (using the procedures presented in Chapter 4) will provide a good indication of the extent of potential impacts.

Step 2. **Existing Noise Exposure**. Estimate the existing noise exposure at each noise sensitive receiver or cluster of receivers using the methods presented in Section 5.1.2.

Projections of High-Speed Rail Noise

Step 3. **Source Reference Levels**. Determine the technology applicable to the project: steel-wheeled high-speed (electric or fossil fuel), steel-wheeled very high-speed, or maglev. For each noise subsource, determine noise exposure in terms of SEL under reference operating conditions. These reference levels should incorporate source-noise mitigation that will be incorporated into the system specifications.

Step 4. **Project Operating Conditions**. Adjust the subsource reference SELs to the anticipated operating conditions of the project (i.e., train consist and speed).

Step 5. **Propagation of Noise to Receivers**. Develop an SEL-versus-distance relationship for each subsource that includes the effects of shielding along the path, as well as any propagation-path mitigation that will be included in the project.

Step 6. **Total Noise Exposure**. Determine total SEL at each receiver by combining the levels from all subsources. Use the SEL to calculate total noise exposure [L_{dn} or L_{eq} (h)] using project operating parameters, including train schedule, speed, and length.

Step 7. **Maximum Noise Level for Train Passbys**. (optional) If determining compliance with vehicle noise limits, project specifications or comparison with measured noise levels is desired, calculate the L_{max} using equations provided in Appendix C.

Noise Impact Assessment

Step 8. **Noise Impact Assessment**. Assess noise impact at each receiver or cluster of receivers using the criteria described in Chapter 3. If a geographic information system (GIS) database is available, incorporating the noise projections and the impact assessment into the GIS database can be an effective means of identifying and displaying where noise impact is expected to occur and comparing the relative impacts for different alternatives. While a conceptual approach for GIS implementation is provided, the details of this process are beyond the scope of this document.

Mitigation of Noise Impact

Step 9. **Mitigation of Noise Impact**. Where the assessment shows impact, evaluate alternative mitigation measures; then loop back to Step 3, modify the project noise computations, and reassess the remaining noise impact. The locations where noise mitigation is needed and any residual impacts with mitigation also can be effectively displayed with GIS databases.

5.1 EXISTING CONDITIONS

5.1.1 Step 1: Noise Sensitive Receivers

The basic steps in identifying noise sensitive receptors are:

- Identify all noise-sensitive land uses.
- Find individual receivers, such as isolated residences and schools.
- Group residential neighborhoods into "clusters" that have similar levels of existing noise and would have similar levels of project noise.

The steps in identifying noise sensitive receivers, both the number of receivers needed and their locations, are shown in Figure 5-1.

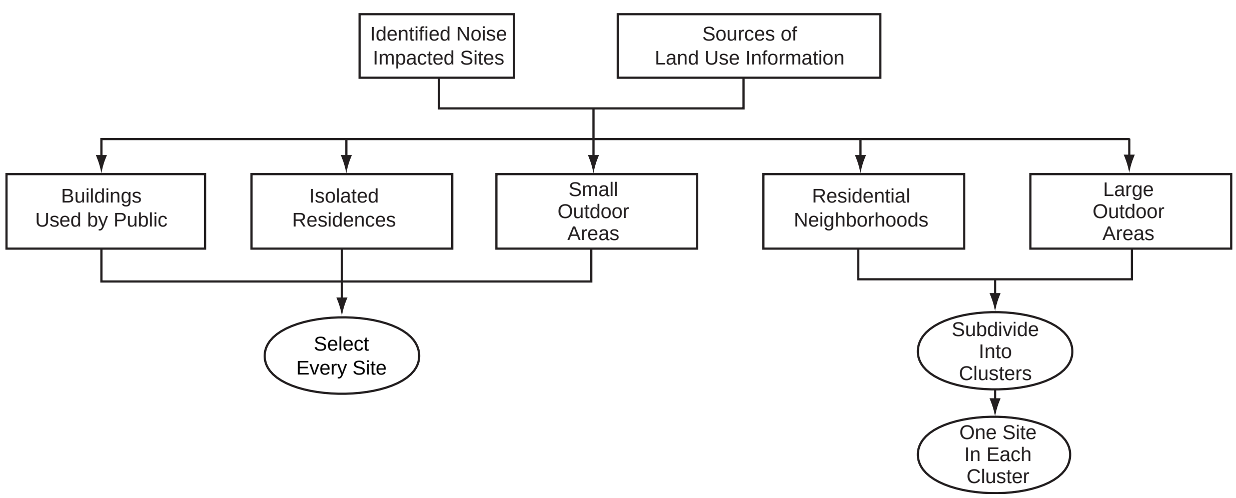

Figure 5-1 Guide to Selecting Receivers of Interest

Identify Noise-Sensitive Land Uses

A Detailed Noise Analysis usually should be performed for all noise-sensitive land uses where impact is identified in a General Noise Assessment. If a General Noise Assessment has not been done, all noise-sensitive sites within the area defined by the noise screening procedure should be included. In areas where ambient noise is low, the assessment will include land uses that are farther from the proposed project than for areas with higher ambient levels.

Three categories of land most likely to be affected by noise from high-speed rail projects are listed in Table 5-1. If noise impact was identified at other types of buildings/areas with noise-sensitive use by the general noise assessment, these types also should be identified.

Table 5-1 Noise-Sensitive Land Uses

Land Uses	Specific Use	Selecting Receivers
Outdoor noise-sensitive areas	• Parks • Historic sites used for interpretation • Amphitheaters • Recreation areas • Playgrounds • Cemeteries	• Select each noise-sensitive site
Residences	• Single family residences • Multi-family residences (apartment buildings, duplexes, etc.)	• Select each isolated residence • For residential areas with uniform noise levels, cluster as described in text
Indoor noise-sensitive sites	• Places of worship • Schools • Hospitals/nursing homes • Libraries • Public meeting halls • Concert halls/auditoriums/theaters • Recording/broadcast studios • Museums and certain historic buildings • Hotels and motels	• Select each noise-sensitive building

Sources of information that can be helpful in locating noise-sensitive land uses in the vicinity of the proposed project include:

- **Land use maps** prepared by regional or local planning agencies or by the project staff. Particularly useful are project-specific maps (track plans, right-of-way plan and profile), which provide building-by-building detail for land uses bordering the project.
- **USGS maps** prepared by the United States Geological Survey, generally at 2,000-foot scale. These maps show individual buildings except in highly urbanized areas, and generally show the location of all schools and places of worship, plus many other public-use buildings. The topographic contours on these maps can be useful for estimating acoustical shielding.

- **Road and town maps**. These maps can supplement the USGS maps. They are generally more up-to-date and may be of larger scale.
- **Aerial photographs,** especially those of 400-foot or smaller scale. When current, aerial photos are valuable in locating potential noise-sensitive land uses close to the proposed project and for determining the distances between receivers and the project alignment.
- **Windshield survey** of the corridor. Definitive identification of noise-sensitive sites often requires driving the corridor and annotating land uses on base maps. Driving the corridor may be the only way to identify new construction, to confirm land uses very close to the project boundary, and to identify site characteristics such as topography and terrain features that are not readily apparent from maps.

Selecting Individual Receivers

Typically, major noise-sensitive public buildings, isolated residences, and relatively small outdoor noise-sensitive areas will be selected as individual receivers. Some judgement in selection is required to avoid a noise analysis where it is obviously not needed. For example, many roadside motels are not particularly sensitive to noise from outdoors. On the other hand, buildings and outdoor areas that the community considers to be particularly noise sensitive must be included. Isolated residences that are particularly close to the project should certainly be included, while those at some distance may often be omitted or clustered together with other land uses, as described in the next section.

Relatively small outdoor noise-sensitive areas should be evaluated using judgement and common sense. For example, playgrounds can often be omitted unless they directly abut the proposed project since noise sensitivity in active playgrounds is generally low.

Clustering Noise-Sensitive Land Uses

Residential neighborhoods and relatively large outdoor noise-sensitive areas often can be clustered, simplifying the analysis without compromising accuracy. These neighborhoods/areas should be subdivided into clusters of approximately uniform noise, each containing a collection of noise-sensitive sites. Uniformity of both project noise and ambient noise should be attained, guided by these receiver-to-source distance considerations:

- In general, project noise drops off with distance from the project. For this reason, project noise uniformity requires nearly equal distances between the project noise source and all points within the cluster. Such clusters will usually be shaped as narrow strips parallel to the rail corridor. Clusters within which the noise exposure will vary over a range of 2 decibels or less are suggested. The fact that noise exposure from rail operations drops off approximately 3 to 4.5 decibels per doubling of distance from the tracks, assuming propagation over open terrain, should be used as guidance. The drop-off will be faster when rows of buildings, terrain, or other obstacles offer acoustical shielding.

- Ambient noise usually drops off from non-project sources in the same manner as noise from project sources. For this reason, clustering for uniform ambient noise will usually result in long narrow strips parallel to major roadways or circling major point sources of ambient noise, such as a manufacturing facility. Clusters within which the ambient noise will vary over a range of 3 to 5 decibels or less are recommended, though this may be hard to judge without measurements.

After defining the cluster, one receiver should be selected as representative of the cluster. Generally the receiver closest to the project and at an intermediate distance from the predominant sources of existing noise should be selected.

5.1.2 Step 2: Existing Noise Exposure

In estimating existing noise exposure, one must first decide whether, and how thorough, a noise survey will be performed. Some noise monitoring should be performed unless extenuating circumstances make measurements impractical. Project schedule, bad weather, and limited budget are typical reasons that measurements may not be possible. The most common approach is to use measurements at representative sites to characterize existing noise. When measurements are not possible, the existing noise exposure can be estimated using Table 4-5 in Chapter 4. A penalty for using the convenient tabular estimates is a built-in conservatism in the projections. That is, the projections under-predict the ambient noise somewhat, and thereby over-predict relative noise impact.

Guidelines for noise measurements to characterize existing noise exposure for both residential and non-residential land uses include:

- For non-residential land uses, measure for 30 to 60 minutes at the receiver, preferably on at least two nonsuccessive weekdays (generally between Monday morning and Friday afternoon). Select the hour of the day when the project activity is expected to be at a maximum.
- For residential land uses, measure for a full 24 hours at the receiver for one or more weekday periods (generally between Monday morning and Friday afternoon).
- Use judgement in positioning the measurement microphone. Location of the microphone at the receiver depends upon the proposed location of the high-speed rail alignment. If, for example, a new rail line will be in front of the house, do not locate the microphone in the back yard. Recommended measurement positions corresponding to various locations of the project source are illustrated in Figure 5-2.
- Undertake all measurements in accordance with good engineering practice, following guidelines contained in ASTM and ANSI Standards.[1,2]

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[1]American Society for Testing and Materials, "Standard Guide for Measurement of Outdoor A-Weighted Sound Levels," E 1014-84, Philadelphia, 1984.

[2]American National Standards Institute, "Method for the Measurement of Sound Pressure Levels," ANSI S1.13-1971 (R1976), New York, 1971.

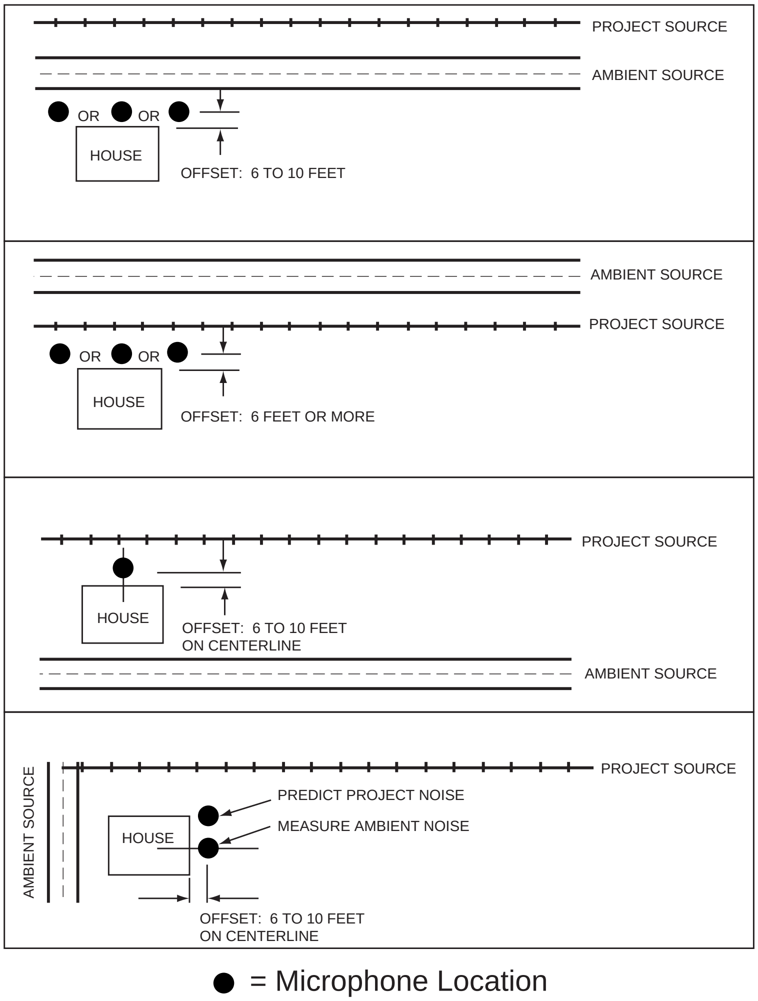

Figure 5-2 Recommended Microphone Locations for Existing Noise Measurements

Measurements made at representative receivers often are used to estimate noise exposure at other similar receivers. In other situations, several hourly L_{eq} measurements at a receiver can be used to estimate L_{dn}. Both of these options require the intuition gained from experience and a knowledge of acoustics to select representative measurement sites.

Measurements at one receiver can be used to represent the noise environment at other sites, but only when proximity to major noise sources is similar among the sites. For example, a residential neighborhood with otherwise similar homes may have greatly varying noise environments. One part of the neighborhood may be located where the ambient noise is clearly due to highway traffic. A second part, toward the interior of the neighborhood, may have highway noise as a factor, but also will receive a significant contribution from other community noise. In a third part of the neighborhood, located deep in